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TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. LIV.

PART E.

Being the fifth volume of the Publications of the
International Engineering Congress,
held under the auspices of the Society,
St. Louis, Mo., October 3d to 8th, 1904.

Edited by the Secretary, under the direction of the Committee on Publications.

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INTERNATIONAL ENGINEERING CONGRESS, 1904.

Organization and Scope.—The Congress was undertaken, financed and conducted by the American Society of Civil Engineers, at the request of the Louisiana Purchase Exposition. Thirty-seven subjects were selected for consideration, and invitations to contribute papers were issued to specially selected engineers in America and abroad ; each of these papers to be a review of progress during the past decade.

Papers and Discussions.—In response to this invitation ninety-seven such papers were received, nearly all of which were printed in advance form and distributed prior to the Congress for the purpose of eliciting discussion. The nationality of the authors of these papers is as follows :

United States, 51,	Holland, 7,	Belgium, 1,	Russia, 1,
France, 18,	Japan, 5,	Canada, 1,	Switzerland, 1.
England, 10,	Austria, 1,	Denmark, 1,	

One hundred and twenty-four additional written communications have also been received, which, together with the oral discussions at the Congress, after revision by the speakers, form part of this Congress publication.

Meetings.—The Congress was divided into eight Sections: Waterways, Municipal, Railroads, Materials of Construction, Mechanical, Electrical, Military and Naval, and Miscellaneous, and twenty-eight sectional meetings were held. There were also two general meetings of the Congress. The total registered attendance was 876, and the average attendance at each sectional meeting about 50.

Publications.—This Volume is one of six containing the Papers and Discussions of the Congress, published by the Society as Parts A, B, C, D, E, and F, of Vol. LIV of *Transactions*. In these volumes although it has not been possible to retain the subdivision by Sections, and no special grouping of subjects has been attempted, the papers and discussion on each subject are grouped. With each volume there is a table of Contents, and the last volume contains an Index covering the entire publication.

CHAS. WARREN HUNT,
Secretary.

NEW YORK, FEBRUARY 25TH, 1905.

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INTERNATIONAL ENGINEERING CONGRESS.

ST. LOUIS, MO., OCTOBER 3d TO 8th, 1904.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

THE SUBSTITUTION OF ELECTRICITY FOR STEAM AS A MOTIVE POWER.

Congress Paper No. 60.

By J. G. White, M. Am. Soc. C. E.,
New York City, U. S. A.

Congress Paper No. 61.

By Alexander Siemens, M. Inst. C. E.,
London, England.

Discussion of the Subject by

Gustav Schimpff, Altona, Germany.
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J. G. White, New York City, U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

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THE SUBSTITUTION OF ELECTRICITY FOR STEAM AS A MOTIVE POWER.

By J. G. White, M. Am. Soc. C. E.

This paper is devoted largely to an epitome of present practice and a review of the work accomplished in America during the past decade, as was requested by the Committee in Charge of the Congress. Illustrations of some important types covered by the title of this paper are found only in Europe, and, consequently, are used.

The title excludes the discussion of urban and interurban tramways; consequently, statistics regarding tramways are used only where they illustrate the possible development of steam lines. As far as possible, the figures used are the results of actual experience or of tests.

A theoretical discussion of an important special case, which might come under the title of this paper, would alone require the full space available for the paper, as it would be of little use unless all the many factors pertinent to the consideration of the problem were gone into in detail. This was well illustrated by a paper, "On the Suppression of the Steam by the Electric Locomotive," presented by Mr. W. Langdon, Vice-President, before the Institution of Electrical Engineers, in London, on November 29th, 1900. This paper and its discussion cover more than 100 pages of the *Journal*

of the Institution, and fully deserve careful perusal. Although of great general interest, the paper is not of great value as a basis of future calculations; partly because it deals only with a special problem; partly, because of some evident mistakes, such as the assumption that the number of trains on a 50-mile section is equivalent to the number passing a given point in one hour, irrespective of their speeds; calculating the required size and cost of the power plant from the average, instead of the maximum, demand for power; the use of a formula for calculating train resistance which gives results less than those which are usually found under actual and ordinary working conditions for self-propelled trains, and that it omits entirely from its calculations the power required for acceleration and the possible economies in labor costs. It is unusually important, in working out a theoretical solution of a given problem of electrification, that all its factors should be carefully studied, because some of the items which may at first seem insignificant are likely, on careful study, to develop greatly in importance. As in other departments of engineering, data secured from commercial operation are more useful than any theoretrical calculations, provided, however, proper allowance is made for all differences in conditions.

Broadly, the advisability of substituting electric traction may be covered by the correct reply to the following question:

"Will the net earnings under electric traction, after making proper allowance for depreciation, be sufficiently increased to meet fully all increased charges for interest and amortization, and leave a larger surplus above fixed charges than is now being earned?"

In answering this question a broad view should be taken, and the future duly considered.

In general, we may assume that, as compared with steam, an electric railway will show the following results:

1.—Large increase in first cost, with corresponding increase in fixed charges;

2.—Considerable or large increase in gross receipts;

3.—Where very few trains are run, increased operating expenses with the same service; but where trains are frequent, decreased operating expenses per car and ton-mile;

4.—In cases specially suited to electric traction (Class "A") large increase in surplus earnings, after meeting all interest and fixed charges, including those on the cost of electric conversion; but, in unsuitable cases (Class "B"), a substantial decrease in such surplus.

The Chicago and New York Elevated Railways, as shown later by operating results, are excellent examples of Class "A," and all engineers who have studied the problem carefully agree that ordinary trunk-line steam railways, under present conditions, belong unquestionably to Class "B."

Between these two classes, there are almost innumerable cases, the proper placing of which can be determined only after most careful study of their respective special conditions. All such examples may be grouped into one large and doubtful class (Class "C").

With a view to determining this classification more readily in any individual case, it is proposed to discuss briefly:

I.—The advantages and disadvantages of electric traction;

II.—The various systems of electric traction available, with their respective advantages, illustrated by operating examples where possible;

III.—The general sub-division of steam roads into classes, with illustrations of results accomplished by the substitution of electric for steam motive power.

It is also proposed to give more specifically the general conclusions briefly stated above, with confirming data where available, and to attempt a brief forecast of the probable development of electric traction during the next few years.

I.—The Advantages and Disadvantages of Electric Traction.

In order to point out or illustrate the many advantages of electric traction, and to acknowledge the directions, beyond lower first cost of equipment, in which steam locomotives are still superior, the following general divisions and sub-divisions have been made:

A.—General Comfort of Passengers.

Experience uniformly confirms the general statement that where any considerable passenger traffic exists this can be substantially increased by the adoption of electric traction. This increase is not due merely to a change in motive power, but to important specific advantages of electric traction, the principal of which are as follows:

1.—Cleanliness.—The elimination of the smoke of locomotives greatly increases cleanliness in traveling. Not only do smoke and cinders drift directly into passenger cars through ventilators and through windows when open, but fabrics used for furnishings and decorations become more or less saturated with soot and soil, by direct contact, as well as by adding dust to the air in cars in transit. The increased cleanliness is particularly noticeable in tunnels, train-sheds and other places where smoke is confined and soot collected.

2.—Ventilation.—With electric traction, generally satisfactory ventilation of trains is easily accomplished. In tunnels and train-sheds, the noxious gases from the locomotive furnaces are entirely absent. In the open, ventilators and windows can be opened to any extent desired by passengers, since they will be bothered neither by gases from locomotives nor by smoke or cinders.

3.—Lighting.—Cars electrically propelled can be readily lighted by electricity in such manner as to secure a thoroughly satisfactory distribution of light; the atmosphere of the cars is heated to a minimum extent by such lighting; and its cheapness, and the ease with which it can be distributed, generally result in a much higher illumination than would otherwise be provided. Electric lighting, of course, is possible on steam-driven trains, but only at much greater first cost of installation, higher operating costs, and generally with less satisfactory results.

4.—Heating.—While much more costly, the electric heating of cars electrically propelled is not prohibitively expensive. To the writer personally, the greatest discomfort incident to steam railway traveling in America arises from the overheating of cars. On one occasion, after being parboiled in a sleeping-car for several hours, a thermometer showed that the temperature under the mattresses of his berth was 145° fahr. While it would be possible to regulate the

heating of passenger cars if steam mains were carried beneath car floors and well protected with asbestos or other heat insulators, the railway companies seem disinclined to adopt this practice, which would permit of small radiators, easily disconnected from steam supply at will. Probably such an arrangement would be less expensive than electric heating; but, as its adoption seems improbable, the advantages of electric heating, permitting of easy regulation and keeping cars at almost any desired temperature, irrespective of general weather conditions, give this feature an importance which, to the mind of the writer at least, deserves substantial consideration.

B.—Speed.

Various contributing factors make a considerably higher speed possible with electric traction on all roads requiring frequent stops, and on others where a large expenditure is justified to secure such higher speeds. The causes making these higher speeds obtainable may be subdivided as follows:

1.—Increased Traction of Rotary Motors.—Much has been said at various times about the increased traction of electrically propelled vehicles, due to the coefficient of friction between wheels and rails being substantially increased by the passage of electric currents. The best evidence does not support the correctness of this theory. It is evident, however, that the irregular torque produced by a locomotive has a tendency to cause its drivers to slip at certain points. With electrically driven wheels an entirely uniform torque is possible, and there is no tendency to slip at particular points of the revolution. For this reason, electrically driven vehicles have a substantially higher traction coefficient. This increase has been stated by Messrs. Potter and Arnold* to be as much as 10 or 20 per cent.

2.—Greater Weight on Driving Wheels Possible.—On many railroads the entire weight of the locomotive and tender varies from 15 to 20% of the total weight of its train. About half the total locomotive weight is usually on the driving wheels, so that the weight on the drivers is usually from 7 to 10% of the total weight of the train. With motors on all axles, 100% of the train weight is on the driving wheels. With a multiple-unit equipment, where half the cars are equipped with motors on each axle,

* *Street Railway Journal*, July, 1902.

approximately 55% of the train weight rests on the driving wheels. If one-third of the cars are equipped with motors on all axles, somewhat more than 35% of the train weight rests on the drivers, and if half the cars are equipped with two, instead of four, motors each, about 30% of the train weight rests on the driving wheels. Electrical equipment, therefore, permits of from three to ten times the proportion of the total train weight resting on the driving wheels which is usual under steam operation.

3.—Increased Acceleration Possible.—The increased traction coefficient of rotary motors, and the increased percentage of weight on driving wheels, explained above, make possible rates of acceleration which cannot be obtained with steam. Rapid acceleration increases greatly the possible average speed of trains making frequent stops. Consequently, it deserves careful study, as it affects greatly, not only the possible schedule speed, but also the first cost of electrical equipment and the cost of power. The importance and bearing of this factor have been pointed out in numerous papers by Messrs. Sprague, Potter, Armstrong, and others, but the space available does not permit of its detailed discussion, in spite of its importance. The importance of a careful study of this subject may, however, be illustrated by figures taken from an excellent paper presented by Messrs. Swinburne and Cooper before the Institution of Electrical Engineers, March 20th, 1902. This paper shows that, in a hypothetical case with high acceleration, about 58% additional energy is required to gain only about 2% in schedule speed. There are other interesting and useful figures in this paper, which are well worth careful perusal. One of its interesting statements is:

"The practical value of high acceleration has been shown very clearly by recent tests on the Liverpool overhead railway, particulars of which have been kindly supplied by the Engineer, Mr. S. V. Cottrell. The total length of the line is 10½ km. (6½ miles), with 17 stations. Up to the present, this distance has been run in 32 minutes, or at the rate of about 20 km. (12½ miles) per hour. Tests with new rolling stock have shown that this time can be reduced to 20.4 min., the time at stations remainiug 11 sec., as before. The total weight of the train, including passengers, during the trial run, was 46.3 tons, the total carrying capacity of the train being 154 passengers. The energy required increased from 250 k. j. per tonne-km. (110 watt-hours per ton-mile) to 310 k. j. per tonne-km. (137

watt-hours per ton-mile); or, 6.35 units per train-mile. The total cost of producing and transmitting this energy would be about 3d. per train-mile."

The net result of the above is an increase of 56% in schedule speed, with an increase in power consumption per ton-mile of only 24½ per cent.

4.—Higher Sustained Speeds Possible.—With the same maximum speed the average speed of a train is affected only by the times allowed for acceleration and retardation, but these are of great importance only where trains make frequent stops. Where its expense is justified it will be possible to attain with electric traction sustained speeds which will practically be controlled only by the perfection of the track available, and the consequent maximum speed which can be run without serious danger of trains leaving the rails. As previously pointed out, it will be possible to have 100% of the train weight on the driving wheels, and, on such trains as the New York-Chicago fast expresses, electric motors could be placed which, in the aggregate, would be enormously more powerful than any steam locomotive which has been built or is practicable under existing conditions. Very high speeds will ordinarily be prohibited by the high resultant costs. Where, however, there are sufficient passengers who are willing to pay substantially to save time, the high speeds possible with electric traction may become important, as, for example, in the much-discussed point-to-point express service between Philadelphia and New York.

C.—More Frequent Service.

One of the most important advantages of electric traction is that a much more frequent train service is made practicable. This permits electrically equipped suburban lines to compete more successfully with trolley roads, automobile or other competing lines, and assists substantially in developing the riding habit of the tributary population. The extent to which traffic can be developed by frequent service is well illustrated by the business of the interurban trolley lines running out of such cities as Detroit, Mich.; Cleveland, Ohio, and Indianapolis, Ind. Some of the roads operating out of Cleveland furnish specific examples.

Cleveland-Oberlin Line.—These cities are 34 miles apart. The competitors for passenger traffic between them and intermediate points are the Lake Shore and Michigan Southern Railroad (steam) and the Cleveland, Elyria and Western Railroad (electric).

In 1895 the total number of passengers carried by the steam railway between these cities and intermediate points was 203 014. This total decreased gradually after the competing electric line was opened to a minimum of 71 755 in 1899, from which it gradually recovered to 91 761 in 1902, but during this same year the electric road carried a total of about 3 000 000 passengers.

Cleveland-Painsville Line.—These cities are 39 miles apart. The competitors for passenger traffic are the "Lake Shore" (steam) and the Cleveland, Painsville and Eastern Railway (electric). In 1895 the steam road carried, between the terminal and intermediate points, 199 292 passengers, but in 1902 it carried only 28 708 passengers, while the electric system carried 1 537 754 passengers.

Cleveland-Lorain Line.—These cities are 26 miles apart. The competitors are the New York, Chicago and St. Louis Railroad (steam) and the Lake Shore Railroad (electric).

In 1895 the steam road carried 42 526 passengers, but in 1902 it carried only 9 795 passengers, the electric road in the same year carrying 3 886 902 passengers.

These specific examples show clearly that the frequent service of the electric lines, and their ability to reach more immediately the points between which people wish to travel, enable them, not only to take a large part of the travel which would otherwise be carried by infrequent steam trains, but to develop new travel, many times greater than the steam roads would be likely to secure without competition. Part of this newly developed passenger traffic, however, is attributable to lower fares, although, even without any great reduction in fares, there has still been a large increase in passenger traffic where a greatly increased service has been initiated.

Mr. W. J. Clark has made some very interesting calculations based on interurban tramway returns for the year ending June 30th, 1902. The summary of his detailed calculations shows that, in his opinion, for that year the electric railroads of the United States did business aggregating $14 086 711, which was taken from steam railroads, and a further $50 495 808 of newly-created business.

The principal contributing causes making frequent services commercially possible may be stated briefly as follows:

1.—Single Cars.—Single cars may be operated at all reasonable speeds with a moderate cost for power, and at wages aggregating those of two moderate-priced men. At moderate speeds the consumption of power by single cars will not be greatly above the power consumption of similar cars operated in trains, but at high speeds, when air resistance becomes an important factor, the power consumption per car-mile of singly operated cars rapidly increases.

2.—Multiple-Unit Operation.—The adoption of a multiple-unit equipment makes it possible to run at any time single motor cars, trains of one motor and one or more trailer cars, or trains made up of combinations of these. Since each motor car, with one or more trailers, is self-propelling, such units can be easily combined and separated. This makes it commercially practicable to operate a reasonably frequent service of shorter trains, even during hours of minimum traffic. The importance of this was pointed out by Mr. B. J. Arnold in his paper presented before the American Institute of Electrical Engineers, in June, 1902. Mr. Arnold gives curves showing the ratio of dead to live weight on suburban and through trains on the New York Central Railroad at various hours of the day. This ratio averaged on through passenger trains 5%, and on suburban trains it varied between 2% at midnight and 20% during the rush hours of the day, the average for the 24 hours being about 11 per cent.

With multiple-unit operation, any such minimum as shown for suburban trains would be entirely unnecessary, and the average ratio of live to dead weight could be substantially raised. The advantages of multiple-unit control are being appreciated more and more. Its advantages, above mentioned, the possibility of advantageously distributing the weight of electric motors required, with minimum addition to the total weight of train, etc., make its use for ordinary suburban passenger traffic seem universally advisable. Even where electric locomotives are used, its adoption is useful, as it will not greatly increase the total cost, and it becomes possible at any time to couple two or more locomotives into one unit, each portion of which will do its proper share of the total work, all being under the immediate and easy control of one engineer.

D.—Increased Capacity of Lines.

In certain cases increased capacity of existing lines, as, for example, on roads having long tunnels, or at terminal stations, where real estate is enormously expensive, may be secured more cheaply by electrical equipment than otherwise. Such increased capacity may be due to any of the following:

1.—Increased Average Speeds.—For reasons already explained, increased average speeds are practicable with a corresponding increase in the number of trains which can be operated over a given track in a given time.

2.—Terminal Capacities Largely Increased.—With the usual terminal arrangements, where one locomotive hauls in a train and another locomotive has to back in, be coupled to the train and take it out, it is almost impossible to operate trains on a given terminal track more frequently than once in from 5 to 8 minutes. With multiple-unit control no more time is necessary than is required for loading passengers, as during that time the motorman bringing in a train can pass to the opposite end, or another motorman can step on the opposite end, and the motorman bringing in one train can take out the following train, the whole operation not necessarily requiring more than one-third or one-half the time above mentioned.

3.—More Powerful Locomotives Possible.—More powerful locomotives are possible, especially by coupling together separate units, each on its own wheel-base, than the most powerful steam locomotives which can be built with existing limiting conditions as to head-room, wheel-base, etc. This was illustrated in the Berlin-Zossen experiments, where a single car, having a capacity of 50 passengers, was able to develop continuously 1 000 h. p. and a maximum of 3 000 h. p.

E.—Economies of Electric Traction.

1.—Power Requirements and Costs.

Wide variations exist in the estimates of power requirements for electric trains. Investigators have frequently failed to appreciate fully the importance of acceleration, length and weight of trains, grades, general excellence of track, and of speed, especially

if sufficiently high to make air resistance and skin friction important factors. The omission of any of these may entirely vitiate calculations based on results experimentally obtained under different conditions. Such omissions probably explain the wide variations above mentioned. For ordinary steam-railroad conditions probably the best data available are contained in a paper presented by Messrs. B. J. Arnold and W. B. Potter at the Nineteenth Annual Convention of the American Institute of Electrical Engineers, June, 1902, entitled "Comparative Acceleration Tests with Steam Locomotive and Electric Motor Cars."*

In the experiments conducted to secure the data included in this paper, similar trains of from one to six cars were hauled by a modern New York Central steam locomotive specially constructed for suburban service and rapid acceleration, having a total weight of about 207 tons and a maximum tractive power of about 26 000 lb., and also by two electric motor cars, each weighing about 35 tons, including electrical equipment, these two cars operating together as one locomotive and hauling the same train of six cars, or parts thereof. In all cases a dynamometer car was placed behind the steam locomotive, or electric motor cars. The general results may be illustrated by Table 1, showing test runs of one mile with maximum rate of acceleration. The tabulated results were obtained against a head wind of 15 miles per hour, with dry rail and a temperature of 8° cent., the grade being practically level, but with a curve in the center of the run, the effect of which was about equivalent to a 1% grade.

TABLE 1.—Test Runs of One Mile with Maximum Rate of Acceleration.

Number of run.	Character of load.	Weight of load, tons.	Total weight, train, tons.	Maximum speed.	Average speed.	Watt-hours per ton-mile, from volt-amperes.
1.....	6 trailers	157	228.5	36.4	27.2	75.9
3.....	5 "	130	201.5	37.9	28.6	78.4
5.....	4 "	104	175.5	39.1	29.8	84.3
7.....	3 "	77	148.5	41.0	30.6	84.7
9.....	2 "	47	118.5	42.8	32.0	98.5
11.....	1 "	23	94.5	44.7	33.1	115.0
13.....	No "	.....	71.5	46.7	34.6	132.3

Street Railway Journal, July, 1902.

Table 1 shows the increased energy required per ton-mile with higher speeds and shorter trains, but only with a maximum speed of 46 miles per hour. This is much more marked with higher speeds, say, 70 to 80 miles per hour. The complete commercial efficiency of a standard electric motor equipment is well illustrated by Table 2, in which the efficiency given in the last column is the ratio between the net mechanical energy output at the driving wheels, as shown by the dynamometer car, and the net electrical energy input, as shown by volt- and am- meters, so that gear and friction losses are included in the loss in efficiency.

TABLE 2.—EFFICIENCY OF ELECTRIC RUNS.

Trailers.	Average miles per hour.	Watts per Ton-Mile.		Efficiency of run.
		Output.	Input.	
6	27.2	59.1	79.8	74.0%
5	28.6	61.0	82.0	74.3%
4	29.8	63.8	84.9	75.3%
3	30.6	68.0	90.2	75.3%
2	32.0	69.6	99.6	69.9%
1	33.1	75.3	112.8	66.7%
0	34.6	79.8	130.0	61.5%

The great increase in energy required at high speeds, especially with light trains, is fully set forth in an excellent paper presented by Mr. A. H. Armstrong before the American Institute of Electrical Engineers, in December, 1903, entitled "High-Speed Electric Railway Problems." A number of interesting and useful curve sheets, based on experiments made by W. J. Davis, Jr., on the Buffalo-Lockport line of the International Traction Company, were presented with this paper and showed the energy required at different speeds with single cars, trains of two cars, and trains of a number of cars, each weighing about 40 tons. According to these curve sheets, for a schedule speed of 30 miles per hour and two stops per mile, the multiple-car train required about 60 watt-hours per ton-mile. With a schedule speed of 45 miles per hour, the energy required was about 92 watt-hours per ton-mile. With a schedule speed of 60 miles per hour, the energy required was about 125 watt-hours per ton-mile. Against this figure

of 125, the two-car train, for the same stops and schedule speed, required about 170 watt-hours per ton-mile, and the single car about 190 watt-hours per ton-mile. The power consumption on the Manhattan Elevated Railway, with a six-car train, having a total weight of about 125 tons, exclusive of live load, and with comparatively low schedule speed, but high acceleration and frequent stops, is reported to be about 125 watt-hours per ton-mile. Including live load, this would be approximately 100 watt-hours per ton-mile.

On the Central London Railway the power required per ton-mile at the contact shoes was reported by Mr. Walton in a discussion before the Institution of Electrical Engineers to be about 50 watt-hours per ton-mile. On the Lancashire and Yorkshire line, recently equipped, the power is reported to be about 80 watt-hours per ton-mile, and on the City and South London Railway the power averages are reported to be 55.2 watt-hours per ton-mile.

The low results on the Central London are secured partly by the grade elevation of stations, which permits of acceleration being partly accomplished by gravity. In this case, also, the station distances are relatively great, and the scheduled speed relatively low.

The *Light Railway and Tramway Journal*, of September 2d, 1904, contains the following table, which seems to conform reasonably to the data at hand:

POWER CONSUMPTION IN WATTS PER TON-MILE WITH AVERAGE SPEEDS OF:

Distance between stops.	40 miles per hour.	30 miles per hour.	20 miles per hour.	15 miles per hour.
3 miles	110	78	53	38
2½ miles	121	83	54	40
2 miles	142	86	60	41
1½ miles	...	95	68	43

2.—First Cost of Electric Installations.

Rights-of-Way, Signaling Systems, and Stations.—It is obvious that the cost of right-of-way, stations, signaling system, etc., will be practically the same for a railroad operated either by steam or electricity, although in some cases it may be found advisable to increase the cost of the signaling system for electrical operation, in

order to secure central or automatic control of trains and increased safety.

Roadbed and Tracks.—The claim is frequently made that roadbed and tracks can be made lighter and less expensive for an electrically operated system than for a steam road, due to lighter maximum wheel weights and the lack of pounding due to reciprocating parts of steam locomotives. This, however, is questionable. With electric operations the speeds and service are generally increased, and consequently the tracks and roadways should be quite as heavy as formerly.

For high speed and rapid acceleration, the best of track is none too good, looking to satisfactory service and reasonable cost of maintenance.

On some new lines a saving can be made by a reduction of curve radius and an increase of maximum grades, but only where first cost is of prime importance.

Rolling Stock.—The rolling stock of an electric road is somewhat more expensive than that required for steam operation. Motor-car trucks will be materially more expensive, and the saving in the cost of locomotives, usually, will not quite balance the cost of the electric motors, resulting in an increased total cost for rolling stock of perhaps from 5 to 15 per cent.

Where an existing steam road is converted to electric traction, the loss is likely to be somewhat greater, as much of the old rolling stock will usually be replaced.

Central Station and Distributing Systems.—The cost of central station and distribution system is the principal charge against an electric equipment, and toward this the steam line has no offset. The central station must be of sufficient size to carry its maximum loads, after allowing sufficient spares. Such a station, under ordinary conditions, will now cost about $130 to $150 per kw. of capacity, including buildings and lands. Modern central-station development tends rather toward increased cost, for the sake of greater operating economies, than to saving in first cost, but the development of the steam turbine is likely to alter this condition. The turbine gives an efficiency almost equal to that of the very best reciprocating engines of corresponding size, and at a cost perhaps 25% less, including savings in buildings and foundations.

The actual manufacturing costs of turbine units are much less than those of slow-speed engines and generators, and this saving is likely to be augmented in the future, and ultimately reduce selling prices.

The total first cost of the station is now practically the same whether direct-current or alternating generators be used. In certain cases, especially where the station load fluctuates badly, it may be advisable to add a battery of accumulators, usually not for economy either in first cost or operating expenses, but chiefly for the insurance and greater reliability of operation secured.

The design and cost of distribution lines depend upon the system adopted, and it is in this branch of the construction of electric heavy traction lines that the most material improvements are to be looked for in the future. With standard direct-current motors and one or more power stations feeding directly into the contact systems or through rotary transformer sub-stations, the total cost of the feeding system for large roads is a very heavy item, but its actual cost can only be determined by careful study of each special case. The system will consist ordinarily of a high-tension distribution line, running at from 10 000 to 20 000 volts, with sub-stations located along the line, containing static and rotary transformers, these sub-stations costing approximately $50 per kw., complete. In view of possible dislocations of traffic, with blocks on certain sections of the line, the aggregate capacity of the sub-stations must usually be considerably greater than the total capacity of the central station. The pressure of the direct current at sub-stations, or at central stations when they feed directly into the line, is limited by the pressure advisable for the motors. Experience indicates that this should not be more than 700 volts, if maintenance accounts are to be reasonable, on account of difficulties of insulation and commutation; consequently, a pressure of 500 to 600 volts has been adopted as standard. The railway contact system, therefore, is expensive for heavy traffic lines, unless sub-stations are very numerous.

The actual contact system may be either from overhead trolley of some form or third rail, the latter being in most cases the cheaper and that more frequently used. On account of danger to employees and the public, and of the difficulties arising from sleet and snow, an improved contact system is very desirable. In Great Britain it

may be required by the Board of Trade, on account of the recent deaths of employees and trespassers from contact with the third rail. This trouble may possibly be met by some form of protected third rail, such protection being preferably vertically above the third rail, so as to protect against weather as well as accidental contact.

In special cases, such as elevated and tunnel railways, the usual third rail may be considered satisfactory, although the Baltimore and Ohio Tunnel uses a sectionalized third rail, each section of which is out of circuit when not occupied by a train.

The cost of the central station and the distributing system is greatly affected by the steadiness and distribution of the load. This total cost is much less over a line of given length operating many comparatively light trains at short intervals and reasonable speeds equally distributed over the route than for the same line operating a few heavy trains of equal aggregate capacity. In the latter case, the fluctuations of load are much greater, the maximum load is likely to be much heavier, and the concentration of load much more severe, requiring larger feeders, sub-stations, etc.

Summarizing, it may be said that, as to the first cost of road-bed, stations, signals and rights-of-way, the costs will usually be practically the same for steam or electric traction; that rolling stock costs somewhat more for the electric system, and that the latter requires a central station and distributing system against which there is no offset. For suburban railways running a 10 or 20-minute service of light trains, this added cost, under average conditions, is likely to be from 20 to 30% of the total cost of a steam line, including rights-of-way, etc.

For trunk lines, where the costs of right-of-way are much lower, and where the frequency of trains is less, the additional cost of electrical equipment is likely to vary from 30 to 60% more than the total cost for steam operation.

J. W. Jacomb-Hood, M. Am. Soc. C. E., of the London and Southwestern Railway, estimates the cost of equipping his suburban lines at £5 000 per mile, and this is probably low.* W. G. Berg, M. Am. Soc. C. E., estimates the cost of an electric main line for through traffic under assumed conditions at $1 857 000, whereas

* *Electrician*, October 17th, 1902

the cost of the same line would be about $610 000 for steam operation. This, however, is an exceptional case. Charles H. Davis, M. Am. Soc. C. E., in a discussion before the American Society of Civil Engineers in 1899,* estimated that the electrical equipment of a complete railway like the New York Central would add about 50% to the total cost of the line, and this estimate, seems to be about right.

The cost of electrically equipping the Manhattan Elevated Railway was about $17 000 000, and the increase of capital due to the electrical equipment was about 20% of the former capital of the line. This percentage is particularly low, as the first cost of the elevated line, including property damages, was extremely heavy.

3.—Operating Costs.

General Expenses.—The general expenses should not be materially affected whether a road is operated by steam or electricity.

Maintenance of Way.—This remains practically constant in either case, although there may possibly be some slight saving in favor of electric traction, due to the lighter trains and better distribution of weight. Maintenance of terminals, due to the absence of smoke and sulphurous acid fumes, should be substantially less.

Maintenance of Equipment.—This item should be materially lower for electrical operation. The maintenance of cars and equipment, other than locomotives, would be somewhat less, due to the absence of smoke, sulphurous acid and other gases, etc.

The cost of maintaining a steam locomotive in good condition is very high, being frequently almost equal to the cost of fuel. For example, in 1903, the Pennsylvania Railway cost of locomotive repairs and all round-house expenses was 9¼ cents per train-mile as against 10.96 cents for fuel. The cost of maintenance of locomotives averages about 20% per annum on their first cost. The maintenance of electrical equipment is very much lower than this. One case is known where an electric locomotive in continuous operation for a year, hauling about 300 000 tons of freight, had a total charge for repairs and maintenance of $88, against a probable corresponding charge of about $2 000 for a steam locomotive of the same capacity. This may be an exceptional case, but it is safe

* *Transactions*, Am. Soc. C. E., Vol. XLII, p. 387.

to assume that the cost of motor repairs will not exceed one-half the cost of locomotive repairs for the same service, and may be less than 25% of such cost. The complete maintenance of equipment account, consequently, should be reduced at least from 20 to 50% by the adoption of electric power.

Against the saving in locomotive maintenance must be put the maintenance of the power station and the distribution system, but this would by no means wipe out the credit with a properly constructed system.

In an elaborate and carefully prepared article on the "City and South London Railway," read before the Institution of Electrical Engineers, December 17th, 1903, Mr. P. V. McMahon states that some of the company's more recent and powerful locomotives have run "13 months continuously without coming into the repair shop for overhauling, the mileage being 46 000."

Fuel Account.—Under average conditions, this account should show little difference between steam and electric operation. A steam locomotive ordinarily will consume from 30 to 80 lb. of steam, and burn from 3.5 to 10 lb. of coal per brake horse power hour.

The electrical central station will produce power with a much smaller fuel consumption per indicated horse power, but the losses in transmission and conversion are so great that much of this saving may disappear.

Below are given the probable efficiencies of transmission and distribution of power from the indicated horse power of the engine to the brake horse power of the motor for full rated and average loads, the latter being, say, about 70% of rated loads.

	Full load efficiency.	Average load efficiency.
Mechanical efficiency of engine....	92	90
Generator	92	90
High-pressure transmission lines..	95	98
Sub-station transformers.....	97	95
Rotary transformers.....	92	90
Low-tension distribution.....	85	92½
Motors	80	75
Total efficiencies.....	48¾	47

Somewhat less than half the indicated horse power of the station engines is thus likely to be available at the motor driving wheels to

propel the train, while locomotives have a total average efficiency of about 65 or 70% (ratio of indicated horse power to draw-bar pull).

While a large high-grade central station should show a fuel consumption of perhaps from 2 to 2½ lb. per i. h. p-hr., the above average efficiencies would require about 4½ to 5 lb. of coal per effective horse-power at the driving wheels. These results are easily attainable with large and economical stations, and very large units, of both turbines and reciprocating engines, can now be purchased with guaranties that they will produce power, under test conditions, with a consumption of not more than from 9 to 10 lb. of steam per i. h. p-hr., or, say, 1¼ lb. of coal per i. h. p-hr.

Messrs. Arnold and Potter, in their paper, mentioned elsewhere, give partial results of a test made with a suburban locomotive making four trips daily between the Grand Central Station, New York City and White Plains, N. Y. This locomotive spends approximately 4 hours per day in actual running, 1 hour per day in shifting, and is idle 19 hours per day. Coal burned during the whole 24 hours is charged, and it was shown that the total fuel consumption was the apparently high figure of 15.6 lb. of coal per effective h. p-hr. at the draw-bar of the locomotive.

These gentlemen assume that the central station can generate power with a fuel consumption of 2½ lb. coal per i. h. p. and a total efficiency (ratio of indicated horse-power to effective horse-power at drivers) of 50%; resulting in a total fuel consumption by electric motors of 5 lb. of coal per effective horse-power at the driving wheels of the motor cars. They, however, estimated that the total cost of power, including interest and depreciation on the electric station and the transmission system, would be about the same for either system.

From considerable data at hand, it is safe to assume that power can be produced in large high-grade stations and delivered at the switchboard at a total manufacturing cost in the United States of from 0.4 to 0.7 cent per kw-hr., and a total cost, including interest and depreciation, of 0.75 cent to 1.25 cents per kw-hr.

It is said that Manhattan Elevated power costs about ½ cent per kw-hr. at the station switchboard and ⅝ cent per kw-hr. at the train shoes, excluding fixed charges.

Car Heating.—This subject should be considered in connection

with the use of fuel. In electrically operated trains, the only efficient and satisfactory method of heating the cars is by electric heaters, and actual tests show that this heating requires from 20 to 28 times the quantity of fuel needed to give the same heating effect as with steam. As on some suburban railroads the power consumed in electric heating ranges from 25 to 50% (the Manhattan Elevated Railway power consumption per car-mile increases about 37% in winter) of the total power consumed on the line during the winter, it is obvious that this uneconomical method of heating may add from 10 to 25% to the fuel costs otherwise necessary. This is likely to be equivalent to from 1 to 3% of the total operating costs. As pointed out elsewhere, the writer believes the advantages of electric heating are sufficient to justify this increased cost.

Wages.—On electrically operated trains for the same service as for steam, wages should be materially lower. If the motorman's cabs are located in the cars, so that a guard, in case of accident, could go into the cab, or otherwise stop the train, and more especially if safety cut-out devices are introduced in the signaling system, only one man is required in the engineer's cab, as is already usual on elevated railways. This man may be less skilled than the ordinary locomotive steam engineer, and, consequently, receives less wages. The presence of a second man is justified only as an insurance against accidents. The wages of other train hands, station attendants, etc., would not be affected. Alterations in the schedule requiring several light instead of one heavy train may, however, increase labor costs. There is another saving in the labor, due to the fact that the electric train is always ready to run. Careful estimates of steam roads show that the locomotive crews are actually running less than half the time they are on duty and drawing wages. The rest of their time is spent in firing up, oiling and cleaning the mechanism of the locomotive, waiting in yards with steam up, and in similar duties. There is also a probable saving in the time of electric trains, in switching and at terminals, resulting in a considerably increased possible daily mileage per motorman. All things considered, locomotive wages may be readily reduced by from 20 to 60% for the same train service.

Return of Power to the Lines on Grades and in Braking.—For many years efforts have been made in electrical systems to devise a satisfactory method for the return of the current to the lines when

the train is coasting on grades, and during the period of braking. With direct-current motors, while this saving is possible, it has not as yet been commercially advisable, nor does it seem likely to be. With the alternating-current motor, as will be shown later, it is possible, under certain conditions, to return to the lines from 5 to 12% of the energy consumed by the train, but at an expense in first cost, complication and danger of breakdown, which is rarely, if ever, justified by the saving.

Possible Use of Cheap Sources of Power.—The economies in favor of electric operation are frequently increased if power can be developed cheaply from water power adjacent to the lines, or from the use of cheap coal, culm, etc. The fuel cost, however, being a comparatively small proportion of the total operating expense of a railroad, this saving is not often sufficient to affect seriously the position, but it is a condition frequently to be taken into account, and justifying careful study.

Possibility of Combining a Power and Lighting Business.—When considering the electrical equipment of branch lines, this should be taken into account, it being sometimes possible to make considerable additional income from the sale of surplus power. As an example, the tunnel equipment in Baltimore may be taken. The demand for power for operating trains is heavy, but irregular, and for a long time the cost of power was reduced very materially by the sale of power to the local tramway for part of its line.

In reviewing briefly the effect on operating costs, it may be said that general expenses and maintenance of way should not be affected, whatever the motive power, but electric motive power should save at least 25% on the maintenance of passenger equipment, something in cost of fuel, and fully 20%, or, if a second man is not put into each cab, at least 60%, of the locomotive wages, due partly to increased mileage.

Mr. Arnold, in a paper read before the Institute of Electrical Engineers in 1902, worked out the total operating expenses per train-mile for steam consumption on the suburban system of the New York Central Railroad, at 23.05 cents, and, for electric operation of the same, 15.8 cents. Adding fixed charges in each case, based on the very low rate of 4%, these figures came out 24.81 cents for steam and 23.03 cents for electric operation.

4.—Relative Reliability.

The steam locomotive has the material advantage of being a self-contained unit, any damage to which affects only the particular unit and train involved, whereas damage to an electrical system, either in the central station or distribution system, is likely to involve trouble over the whole, or at least over a considerable section of the system.

On the other hand, there is much less danger of a complete breakdown with electric motors than with steam locomotives, damage to one motor, which can readily be cut out, not affecting the operation of the train materially.

In a properly designed and constructed distribution system the probability of a total breakdown is very small, and in a good central station equipped with sufficient spares, there is almost no danger of interruption of supply. With the use of a third-rail system, there is greater danger of interruption to traffic, due principally to snow and sleet on the line, but undoubtedly this will be lessened with improvements in the protection of the rail and of contact devices. On the whole, it is safe to say that electric is already nearly as reliable as steam operation.

5.—Relative Safety of Steam and Electrical Systems.

With the same signaling appliances and conditions of operation, the safety of train operation by steam or electric systems should be the same, except in special cases, such as tunnel or underground roads. In these cases, the safety is much greater with an electric system, because there is no steam or smoke to obscure the signals, train lights, etc.

With an electric system, however, it is readily possible to increase safety by controlling the trains automatically by the installation, at the end of each block, of automatic devices for cutting off the current if a train runs past its signal.

Risks from fire have probably, up to date, been considerably greater with electric than with steam traction, particularly on elevated or tunnel roads, as illustrated by the Paris accident. The fatalities connected with this accident seem to have been entirely unnecessary. They would probably have been prevented had there been an independent lighting system, so that the passengers could have found their way promptly to the surface, the deaths having

been largely those of passengers who were trying to force their way out where there was no passage. Besides this, the construction of the cars was faulty, and the wiring very badly done. Among the precautions which should be taken to minimize fire risks may be mentioned:

1.—In tunnels and at stations there should be a lighting system entirely independent of the current furnished for train operation.

2.—Cars running in tunnels or on elevated roads should be made fire-proof so far as possible, particular care being taken to see that all portions of the car which might be reached by flames from short circuits are fully protected by asbestos or other fire-proof material.

3.—Wires carrying heavy currents should not run from one car to another.

4.—All wires which through any possible accident may carry heavy currents should run in a properly designed system of fire-proof tubing.

5.—All fuses, circuit breakers, or other safety devices should be enclosed in fire-proof cases and placed so that, under no circumstances, would any arc which might be formed by heavy currents set fire to any inflammable portion of the car.

6.—In tunnels, especially, the system of contact conductors should be divided into short sections, so that the massing of trains on any one of these will not require the concentration of an excessive amount of power. By thus dividing the contact system into short sections, at a somewhat increased cost for feeders, it will be possible to protect each section automatically against an excessive flow of current, thus removing the source of continued serious short circuits on any train.

Other precautions will suggest themselves to engineers studying this problem carefully with reference to a particular installation.

If these, and such other precautions as seem locally advisable, are taken, risks from fire should not be substantially greater with electric than with steam traction.

II.—Available Systems of Electric Traction.

Since the transmission system is dependent upon the type of generators used in the central station, it is perhaps best to subdivide this topic into only two divisions, *viz.:*

A.—Stations and Distributing Systems; and
B.—Car Equipments.

A.—Station and Distributing Systems.

To simplify discussion, this subject is subdivided as follows:

1.—Direct-Current Generating and Transmission.

This system is in use on some of the short branch lines of the New York, New Haven and Hartford Railroad which have been electrically equipped, and elsewhere it is the standard for urban tramways in cities of moderate size, and for many interurban roads as well.

For existing steam roads, direct-current generators (in a single station) merit serious consideration only when it is unnecessary to transmit current more than 6 or 7 miles from the central station. Usually this system includes direct-current generators developing about 600 volts pressure, driven by reciprocating engines of low or moderate speeds, turbine speeds being ordinarily too high for satisfactory operation of direct-current generators.

The current is carried by feeder lines directly to properly located points, where it is fed into the trolley wire or third rails forming the contact system. In special cases, a greater range of territory may be secured by the use of "boosters," or by a three-wire distributing system, modified as may seem advisable in each particular case. The most elaborate and extensive illustration of such a modified direct-current system is on the City and South London Railway, which was described in detail by Mr. McMahon in a very interesting paper presented before the Institution of Electrical Engineers, December 17th, 1903. Five hundred volt motors are operated on the three-wire system from conductors having a difference of potential of 1 000 volts, running rails forming the neutral conductor. An additional saving in the feeding system is accomplished by motor-generator reducers at sub-stations, which are fed at 1 000 volts above the rail potential, or 2 000 volts across the "outers." Storage batteries are also included to equalize current demands and minimize transmission losses. The resultant average transmission and transformation efficiency over the whole system is very satis-

factory, being more than 91%, but ordinarily such an elaborate system would not be justified.

2.—Alternating, Generating and Transmission.

This may be considered the standard system for the equipment of steam railways, the direct-current system being advisable only in exceptional cases. This system is in use on such roads as the Manhattan and other American Elevated Railways, the Tyneside lines of the North Eastern Railway, and the Liverpool Suburban section of the Lancashire and Yorkshire Railway, mentioned elsewhere. Alternating generators are being installed also for the large terminal equipments of the New York Central and Pennsylvania Railroads at New York. In this connection it may be interesting to mention the results of some careful calculations included by Mr. B. J. Arnold in his paper presented before the American Institute of Electrical Engineers, June, 1902, for the operation of the New York Central trains between the Grand Central Station and Mott Haven Junction, this paper giving the estimated total operating cost per train-mile, including interest on the investment at 4% per annum, as follows:

1.—For a single direct-current station located near the center of the line, 20.6 cents;

2.—For a combined alternating and direct-current station located on the Harlem River, with one sub-station, 21.18 cents; and

3.—For the system just mentioned, with storage battery added, 23.63 cents.

In spite of these differences, Mr. Arnold recommended the adoption of the third plan, the first being ruled out because satisfactory land for a station could not be secured near the center of the line, the added cost of the battery being recommended because of the greater reliability and security in operation which would result.

Later, it was decided to operate trains electrically for a much greater distance, so that the alternating, generating and distributing system has marked advantages. The station will contain numerous alternating turbo-units of 5 000 kw. each. Turbine units of

about the same size have been decided on also for the Pennsylvania Railroad equipment.

In the above, and the following, remarks, the distributing system referred to includes the static transformers located in the sub-stations and the conductors between them and the generators. Beyond the static transformers the distributing system will depend on the motors used, and the secondary system of conductors is consequently grouped, for discussion, with the motors.

As between these two systems the direct current has the one great advantage, *viz.*, that the current can be distributed directly from generators to motors with a simple low-pressure, but expensive, system of conductors.

The alternating system has the following disadvantages:

Average Transmission Losses.—In the direct-current conducting system the transmission losses are easily restricted to, say, 15%, but the alternating system will, under usual conditions, show a combined loss in primary and secondary distribution and static transformers of, say, 17% for alternating-current motors, and a probable loss of, say, 24% for direct-current motors, rotary transformer losses being then included.

Sub-Stations Necessary.—Sub-stations, including always static transformers, and, for direct-current motors, rotary transformers as well, are necessary. These entail increased first cost and fixed charges, as well as maintenance and attendance charges.

On the other hand, the alternating, generating and distributing system has the following advantages:

Distribution.—The distribution of electric power over a large area is practicable from a single generating station at moderate cost. With direct current, such cost would be frequently prohibitive.

Generating Station.—The generating station may be located where coal can be most readily and cheaply delivered, and where water is available for boiler and condensing purposes, without greatly increasing the cost of the conducting system.

In American practice, it may be said that the apparatus for this system is largely standardized. This includes alternating generators, direct driven by turbine or reciprocating engines, generating currents having a frequency of 25 cycles, and such voltage as may be decided on. For moderate transmission distances, this volt-

age is likely to be 5 500, 6 600, or 11 000 volts without step-up transformers, but for long distances lower voltage generators and step-up transformers, should result in primary line pressures of from 20 000 to 50 000 volts. So far as is known, these highest transmission pressures are not yet in actual use for traction purposes, but are just as applicable to the current for traction as for other purposes. Substations include step-down and rotary transformers, from which direct current is distributed at about 600 volts pressure.

B.—Motor Systems with Accompanying Secondary Transmission Systems.

As stated in previous paragraphs, American practice to date includes only the direct-current traction motors in daily commercial use. For the purpose of this discussion, traction motors may be divided into four classes:

a.—Direct-current motors;
b.—Three-phase motors;
c.—Single-phase motors;
d.—Miscellaneous proposed or experimental systems.

Direct-Current Motors.—Perhaps the universal use of direct-current traction motors in America is due principally to the following causes: First, that, in the early development of electric traction, American electrical engineers learned that simplicity and reliability are paramount to total first cost of installation; second, that the leading electrical manufacturers have been able to furnish direct-current motors, and, consequently, had no undue reason to press the sale of alternating motors; and, third (and principally), because even up to date no alternating-motor system has been designed which for general excellence and efficiency is equal to the standard series direct-current motors with series multiple control. More specifically, the advantages of the direct-current motor may be stated as follows:

1.—Comparatively high average efficiency, the latter being, for well-designed motors operating under average conditions, approximately 75% of the total commercial efficiency, the 25% loss including gear and friction losses;

2.—Very high starting torque, torque and current consumption both decreasing automatically with increase of speed;

3.—Heavy overload capacity for short periods;

4.—Simple and efficient method of speed control, standard series parallel system;

5.—Comparatively cheap and simple construction, and light weight of motors.

On the other hand, the working pressure advisable for direct-current motors is limited to 600 or 700 volts, above which maintenance charges increase rapidly, due to insulation and commutation difficulties. At about 600 volts, or less, however, repairs and maintenance charges are very moderate, if motors are well designed and constructed.

Three-Phase System.—This system has been much discussed, but seldom installed. A most lucid and logical discussion of this subject is contained in a paper read before the Manchester Local Section of the Institution of Electrical Engineers, on December 15th, 1903, by Mr. A. C. Eborall, entitled "Electric Traction with Alternating Currents."*

Although showing perhaps a slight bias toward alternating-current motors, Mr. Eborall is very fair in his conclusions, and the paper well deserves careful reading.

The disadvantages of the three-phase motors are as follows:

1.—Efficiency, including controlling system, lower than direct current;

2.—Increased weight and cost over direct-current motors of the same power, approximately 25 per cent.;

3.—Poor starting torque, which decreases proportionately with drop in voltage (and the drop in voltage is greater than with direct current, due to low power factor at starting and poor generator regulation);

4.—Tendency to operate at a constant speed, nearly in synchronism with the generator, resulting in overloading motors on up grades. To obviate this, the Burgdorf-Thun line has two interchangeable gear ratios, the disadvantages of which will be recognized by those who have had much experience with operating movable gear trains;

* *Electrician*, December 18th, 1903.

5.—Low-power factor, which, under ordinary working conditions is likely to approximate 50%, requiring generators, transformers and transmission lines to be much larger than would otherwise be necessary;

6.—Three trolley wires, or two trolley wires and track return, are required, adding complexities which become serious at terminals and switching points;

7.—Decrease in the carrying capacity of rails and conducting system, due to self-induction, eddy currents, etc. Experiments recently reported by the General Electric Company state that the carrying capacity of the two trolleys and double track was 1.76 times as great with direct as with alternating 25-cycle current, and with direct current the track alone had a carrying capacity 6.55 times as great as with alternating current. This, with the low-power factor elsewhere referred to, requires a much greater investment in the conducting system than would be required with direct current of equally high pressure, if it could be used.

The advantages of the three-phase system are:

1.—The possibility of using high pressures at motor terminals, limited by the difficulties of the insulation and maintenance to about 2 000 or 2 500 volts.

2.—Decreased cost of the secondary conducting system, due to ability to use the voltage above mentioned. The full benefit of this, however, is prevented by the low-power factor and induction losses.

3.—The possibility of returning the current to the line during retardation periods between synchronous and half speeds, and on down grades, when running above synchronous speed.

The former is possible only if the "cascade" control, described later, is used.

The energy which can be returned in this way is ordinarily restricted to from 6 to 12% of the total energy required, and the complications introduced are such as, in the opinion of the writer, make this quite inadvisable under usual conditions.

Where very frequent stops are required, a somewhat greater return of the current to the line will be possible, but here the advantages of direct-current motors are so pronounced as to make the use of any alternating system of motors inadvisable.

4.—Sub-stations need contain only static transformers, and, con-

sequently, can be operated without attendance other than an occasional inspection.

There are two control systems for three-phase motors in commercial use, the first of which regulates the speed of the motors by the introduction of resistances in the rotor circuit. These resistances must be heavy and expensive in order to carry sufficient current to make them effective, and there is little or no saving in power when running at less than synchronous speed. The Burgdorf-Thun road is the most noted example of this system of control.

In the second system, speed control is secured by arranging motors in "cascade" or "tandem." This system is in use on the "Valtellina" or "Lecco" line in Italy. This equipment, as well as the equipment of another somewhat similar steam road in the same neighborhood in Italy, operating with direct-current motors, was ably described by Professor Carus-Wilson in a paper read before the Institution of Electrical Engineers, May 15th, 1902. Much interesting data and some interesting comparisons between the two motor systems are contained in this paper. Briefly, the "cascade" system introduces secondary motors which are used only at starting, during which time they take the place of the resistances of the other system, thus utilizing the current from the rotors of the principal motors, which, in the other control system, is wasted in the rheostat.

The increased cost and weight, the lower power and maximum speed shown, complex controlling devices and the other disadvantages above mentioned, make the use of this system ordinarily inadvisable.

The comparative merits of the direct-current and three-phase systems are partly shown in the brief table on page 33, taken from Professor Carus-Wilson's paper.

In exceptional instances, where there are extended continuous heavy grades, the possible return of current may justify the serious consideration of three-phase motors, but, in the opinion of the writer, the use of these motors will rarely be admissible.

Single-Phase System.—Several of the principal electric manufacturing companies state that they are now prepared to furnish single-phase motor equipments, from which excellent results may be expected. These include the Allgemeine Company of Germany, the

Westinghouse Company and the General Electric Company. The single-phase system of the Westinghouse Company has been described by Mr. Lincoln. The motor is similar to an ordinary direct-current motor, but with laminated fields, smaller air-gap and other modifications of design which permit it to operate on alternating currents, with characteristics approximating those of a direct-current motor.

COMPARISON OF WEIGHT, POWER AND DIMENSIONS OF THE POLYPHASE MOTOR CARS ON THE LECCO LINE WITH THE DIRECT-CURRENT MOTOR CARS ON THE VARESE LINE.

	Total weight empty, in tons.	Length of frames, in feet.	Seats.	Number of motors.	Maximum h. p. of each.	Total maximum h. p.	Weight of four motors, in tons.	Full speed on level, in miles per hour.
Varese.....	40	52	63	4	150	600	10	56
Lecco.....	53	57	56	4	2 of 150 2 of 75	300	15.2	37

The system of the General Electric Company is quite fully described in the *Street Railway Journal.** Pictures of the car and motor, with speed-time curves, characteristic curves, etc., are included. A public test of this equipment was recently made on the Ballston Division of the Schenectady Railway. This motor is of the compensating commutator type, the field windings being so arranged as to neutralize or compensate for armature reactions, the result being that the armature acts almost equally well with direct or alternating current. This permits the car to operate over the direct-current lines in Schenectady at the usual pressure of 600 volts, and, at the same time, permits it, when it reaches the Interurban Section, to operate from a trolley wire carrying an alternating current at a pressure of 2 200 volts, a static transformer which is carried under the car reducing the pressure to 400 volts, at which the motors operate with alternating current. The torque and

*August 27th, 1904.

efficiency characteristics of this motor are very similar, whether operating with direct or alternating current, the alternating efficiencies, however, being somewhat lower, and the power factor shows the high average of from 90 to 95% under ordinary conditions. This motor is controlled from the regular direct-current controller, an interlocking switch, however, being used to throw in the step-down transformer, and to change over connections when the motor is to operate from the alternating trolley wire. The motor has a considerably smaller air-gap than a standard direct-current motor. This weakness is incident to all alternating-current motors, and might have been mentioned under their general disadvantages, since bearings must be very carefully watched and frequently renewed, or refilled, in order to prevent sagging of and damage to armatures.

Unless unforeseen weaknesses develop in operation, this motor, including its control, has so many advantages as compared to three-phase motors that the latter seem clearly to be "outclassed." For lines operating an occasional service over routes running to considerable distances from the generating station, its use may be advisable and deserves careful consideration. The space devoted to this motor does not imply that similar equipments of other manufacturers are not equally good, but the writer has not seen such detailed descriptions, nor such convincing data as the characteristic and speed-time curves above referred to.*

Experimental Systems.—If the single-phase motor is commercially as well developed as the data above referred to would indicate, the following and other experimental systems are not likely to be adopted extensively. Among the interesting proposed or experimental systems may be mentioned that of Mr. B. J. Arnold, in which an alternating-current motor is operated at constant speed and drives an air compressor to fill a reservoir from which an auxiliary air engine is operated to assist the motor during the periods of acceleration or other special times.

* The report has just been received that the first single-phase motor equipped road of the Allgemeine Company has been run for six weeks at Innsbruck. The operation has been entirely satisfactory from every point of view, and the Allgemeine Company is satisfied that its single-phase motor is now a commercial success. This motor, sometimes known as the Eichberg motor, has not been described in detail in this paper, but it is very similar in its characteristics and construction to the General Electric motor which is described. The Allgemeine Company has been experimenting with this motor in its shop for about two years, and the result is the equipment of the above-mentioned road.

The system designed by Mr. H. Ward-Leonard includes an alternating motor carried on the car or locomotive which drives a direct-current generator, the current from which drives direct-current motors mounted in the usual way. This gives an ideal control, but the added cost and weight of the extra motor-generating set, and the difficulty of finding space for it prohibit the general use of this system. Other examples might be mentioned, but would probably be of historical or theoretical, rather than of practical, value.

III.—General Subdivision of Steam Roads and Results of Change to Electric Traction.

Previously in this paper, steam roads have been arbitrarily grouped in three general classes as follows:

Class A.—Electrification clearly advisable;

Class B.—Electrification inadvisable under existing conditions and development of the art;

Class C.—Electrification of doubtful value, to be determined only by a careful study of the special conditions appertaining to each individual case.

These general classes may be sub-divided to almost any extent desired. For purposes of discussion, the following subdivision may be adopted:

Class A.—Electrification Clearly Advisable.

1.—For Lines Operating Very Frequent Trains and Having Numerous Stops.—Excellent examples of this type are found in the elevated railways of Chicago, New York, Brooklyn, Boston and Liverpool. That electric traction is undoubtedly advantageous in these cases is readily shown by the data in Table 3, giving actual results on the South Side Elevated Railway of Chicago and the Manhattan Elevated Railway of New York City.

2.—For Tunnel Roads.—Where electrification is advisable for the sake of ventilation, irrespective of operating costs. Examples of this class are the Baltimore and Ohio Tunnel equipment at Baltimore, the City and Waterloo, the City and South London and the Central London Railway, of London, etc.

TABLE 3.—Statistics of South Side Elevated Railway and Manhattan Elevated Railway.

	South Side Elevated Railway, Chicago.	Manhattan Elevated Railway, New York.
Date of figures "before" electrification	1897	1900
" " " "after" "	1899	1904
Cost of electrical equipment, about	....	$17 000 000
Power consumption per ton-mile (in summer), about	.....	125 watts
" " " " " (in winter), "	.....	171 "
Increase for heating, etc., about	.....	37%
Gross receipts "before" electrification	$695 287	$9 969 900
" " "after" "	1 170 381	14 529 188
Increase	475 094	4 559 288
Percentage of increase	68%	46%
Operating expenses "before" (including taxes)	$562 258	$6 104 293
" " "after" "	*669 933	†6 717 726
Increase	107 675	613 433
Train-miles run "before" (Manhattan 5-car trains)	.....	10 740 183
" " " "after" " 6-car "	.....	11 000 000
Total net earnings "before" (taxes and operating expenses deducted)	$133 029	$3 865 007
Total net earnings "after" (taxes and operating expenses deducted)	500 448	7 811 462
Increase	367 419	3 946 455
Percentage of increase	276%	102%
Percentage of excess earnings on cost equipment	.....	23.2%
Percentage of operating expense to gross receipts "before"	81%	61%
" " " " " " " "after"	57%	46%
Saving per car-mile in operating expense	.....	9.6%
Excess cost per car-mile in operating expense and fixed charge (interest and depreciation) calculated at 7% on $17 000 000	.....	7%

* Loop rental included as an operating expense.
† Taxes for 1904 estimated to be the same as in 1900.

3.—For Terminals in Large Cities.—Especially if partly operated through tunnels, where the numerous advantages of electric traction make its use advisable. Important examples of this type are the large installations now under way by the New York Central and Pennsylvania Railroads in and near New York City.

4.—For Lines on Which, from Franchise or other Conditions, the Use of Steam is not Permissible.—An example of this type is an American road operating a line 6 miles long, and hauling over this line about 300 000 tons of coal per annum by electric locomotives. Power is purchased at 1½ cents per kw-hr., or about 50% above cost of generation, including interest and depreciation. The cost per ton-mile is high if compared with long-haul trunk-line figures, but, for 1903, the operating expenses were less than 25% of the gross receipts. Electric locomotive repairs aggregated for the year, $88.02.

Operating expenses for 1903 were:

Maintenance of way	0.4136	per ton-mile.
Maintenance of equipment:		
Electric locomotive	0.0032	" " "
Cars, etc	0.1056	" " "
Transportation	0.16	" " "
Power purchased at 1½ cents per kw-hr	0.1088	" " "
General expenses	0.2112	" " "
Total operating expenses	1.0024	" " "

and the manager of the property estimates that the road could be operated by steam at about the equivalent of 1 cent per kw-hr. for electric power, or about the actual station cost, including the interest and depreciation of such power. On account of the slight saving, he would prefer steam operation, but says:

"As a matter of convenience, however, there is no comparison between steam and electricity. The electric locomotive is always ready on the instant, without firing up, never needing boiler cleaning and never having danger of freezing water in boilers or many of

the other inconveniences that come with the use of the steam locomotive."

Class B.—Electrification at Present Inadvisable.

1.—On All Trunk Lines.—When operating under usual conditions and normal distribution of passenger and freight traffic.

Generally, it may be assumed that trunk lines operating trains at a headway of more than 30 minutes, cannot show sufficient economies and gains of traffic by electrification to cover the interest and depreciation on the cost thereof. With trains operating more frequently than with 30-minute headway, individual cases may merit detailed study.

2.—On Branch Lines.—When depending largely or entirely on freight traffic, and on other branch lines on which a very substantial increase in passenger traffic cannot be developed by such more frequent service as electric equipment would make readily possible.

Class C.—Electrification of Doubtful Value.

1.—For Ordinary Suburban Traffic Radiating from Large Cities.—Where distribution of population, possible increase in passenger receipts by higher speeds, better and more frequent service, increased possible use of available terminal facilities and other factors must be carefully stated to determine the probable actual results.

As examples of this kind the suburban lines of the Illinois Central Railroad in and near Chicago may be mentioned, the electrification of which has been much discussed and most elaborately estimated upon. It seems probable that in this case electrification is now fully justifiable. Other examples may be found in the suburban business of the Pennsylvania and Reading Railroads of Philadelphia, of the Great Eastern and Southeastern suburban lines running out of London, etc.

Examples of this class where, after careful study, electrical operation has been adopted are the Lancashire and Yorkshire suburban line out of Liverpool and the Northeastern Railway suburban lines at Newcastle-on-Tyne.

2.—In Cases Where Increased Capacity is Required, and Is Possible Only at a Large Cost with Steam Operation.—This would include lines having very expensive terminal facilities not otherwise easily increased, and lines having expensive routes, such as tunnel sections of mountain divisions, where additional tracks could be added only at enormous expense. A very interesting example of this class was discussed by Cary T. Hutchinson, Assoc. M. Am. Soc. C. E., in the *Electrical Age.** In this case, the problem to be considered was to provide for an increase of 50% in the freight-carrying capacity of a mountain division approximately 80 miles long, and having at one end an ascending grade averaging about 2½% for nearly 20 miles, and, at the other end, a descending grade some 14 miles long. Heavier locomotives were not permissible, because of the sharp curves limiting the rigid wheel base to a maximum of about 10 ft., and as two, and sometimes three, locomotives were already in use per train, an increase in this direction seemed inadvisable. There were special features favorable to electric traction, such as the fact that the power-house could be located near a coal mine owned by the company, where coal could be secured at about 75 cents per ton, and where water for condensation was available. The service under consideration included the transportation of about 50 000 tons of freight per day over this division. The total estimated cost of this proposed equipment is put at from $7 000 000 to $8 000 000, depending on details adopted. Based on a careful study and a comparison of the two services, the following results were reached:

	Steam.	Electric.
Tonnage	51 000	51 000
Mileage per day	6 500	2 100
Cost per train-mile (electric trains much heavier)	$0.495	$0.685
Cost per day	3 220	1 440
Saving by electricity per day	.....	1 780
Saving by electricity per year (about 8 to 9% on cost)	.....	650 000

Dr. Hutchinson mentions additional minor and incidental advantages of electric traction, and concludes that "under some conditions even the hauling of heavy freight trains by electricity may be well worth serious consideration."

Another example under this class, which has been much discussed, is the steam railway between Milan and Genoa, including a tunnel some six miles long, where increased capacity is urgently needed. In this case, the electrical equipment is estimated to cost less than the building of a second tunnel, and, at the same time, would be more satisfactory, eliminating the bad ventilation of the existing tunnel.

3.—For Operation of Passenger Service.—On short branches with frequent trains or cars, where power can be obtained cheaply, sometimes from street railways controlled by the steam railroad company, or otherwise, as for example, from developed water powers in the neighborhood. An excellent example of this type may be found in the section of the Erie Railway from Tonawanda to Lockport, N. Y., formerly operated at a loss by steam, which was electrically equipped in 1896 or 1897, and is now operated as a portion of the International Traction Company. "Over it were operated two passenger trains daily in each direction, carrying an average of less than 200 passengers per day. It now carries over 3 600 passengers daily, besides doing a large and profitable freight business."

4.—For the Handling of All Trains over Lines Having Infrequent Service.—Where coal is unusually expensive, and where cheap and reliable water power is available.

Although frequently referred to in general discussions, examples of this type are extremely rare, if they exist at all, simply because the increased fixed charges will usually exceed any possible increase in earnings from operation.

5.—For Lines Having Infrequent Steam Service.—Where passenger traffic can be greatly increased by more frequent electric service, without greatly increasing operating costs. In such cases, the entire traffic may be operated electrically, or all freight traffic may be operated by steam, either at night or between electric cars, and the entire or local passenger business may be done by electric cars

operating over the same track. An interesting example of this type is found in the steam railway operating out of Quebec, described in an article published in the *Street Railway Journal*.* In this case some 30 miles of track were electrically equipped for the extremely modest sum of $170 000, the trolley wire being strung at sufficient height so as not to interfere with brakemen or others on freight trains. The former steam passenger and freight service has been maintained, and an hourly or half-hourly electric service has been sandwiched in. The total number of passengers carried increased from 253 054 in 1899 (by steam) to 571 374 in 1901 (steam and electric), the passenger revenue being increased by $29 071.39, with an increased expenditure of only $5 698.46. For the next year there was a further increase of some 90 000 in passengers carried.

Other interesting examples of this type were ably described in detail by Professor Carus-Wilson in his paper before referred to. The traffic receipts on these lines were extremely light, but the cost of electric conversion was about $25 000 per mile. In order to develop greater passenger traffic, it was proposed to change from 8 ordinary to 28 short trains per day on one line and to a somewhat similar increase on the other. To show equal net results, after charging interest at only 3½%, Professor Carus-Wilson estimated that the passenger traffic on the "Gallarate" line would have to increase 129%, operating with a steam generating plant, or 80% with hydraulic operation, and on the "Lecco" line, operating with water power, an increase in passenger receipts of 128% was necessary. Before proceeding with these installations, an experiment had been made on a shorter line, on which both speed and frequency were doubled, fares were reduced about 40%, and passenger receipts were doubled. As it was announced a few months ago that both of these lines are to be extended, it would seem that the required increase in receipts has been realized.

6.—For the Handling of All Passenger Traffic between Large Cities.—Where this is sufficiently concentrated to justify the large expenses of specially constructed or high-speed lines. Examples of this kind, which have been discussed for some years, are the projected lines between Philadelphia and New York, Philadelphia and Atlantic City, Liverpool and Manchester, and Berlin and Hamburg.

* June 28th, 1902.

Preparatory to an intelligent discussion of the last-mentioned case, exhaustive experiments were made under the auspices of the German Government on the Berlin-Zossen line, which are well known and referred to elsewhere in this paper.

IV.—Summary of Conclusions with Reference to the Advisability of Substituting Electric for Steam Traction.

1.—Increase in Gross Receipts.—There should always be a substantial, and, under favorable circumstances, a very large increase in gross receipts, due to specific advantages of electric traction, among which are:

a.—Increased general comfort of passengers, contributed to by greater cleanliness, better ventilation, more brilliant and better distributed lighting, and more equable heating of cars;

b.—Higher speeds, due largely to increased accelerations, rather than to higher maximum speeds. Such accelerations are attainable because of increased traction coefficient, due to uniform torque, use of powerful motors, and to greater weight on driving wheels;

c.—More frequent service, either with single cars which can be operated at a cost justified by their earnings, or by trains operated by multiple-unit control of such length as will accommodate the changing volume of traffic.

2.—Increase in Capital Invested and Fixed Charges.—There will be a considerable increase in capital invested, with a proportionate increase in fixed charges.

The total cost of rights-of-way, road-bed, tracks, stations, signaling systems and similar minor items should, although differing in detail, be substantially the same.

The cost of rolling stock should be nearly the same, although electric motors and trucks, with their accessories, usually cost slightly more than locomotives of the same aggregate capacity.

The cost of central power station and of distributing and contact systems is a large item, against which steam equipment has ordinarily no countercharge.

In exceptional cases, increased capacity of lines and terminals may be secured by electric equipment with less investment than in any other way. Such increased capacity will be due principally to the higher average speeds, making it possible to run more trains; to the more rapid operation of trains into and out of terminals, increasing their capacity by as much as 100%; or to the use of electric locomotives more powerful than any steam locomotive which can be constructed under existing limitations.

3.—Decrease in Operating Costs.—The operating costs on exceptional roads will be decreased somewhat under electric traction. On other lines, still favorable to electric traction, operating costs will increase, but the gross earnings will be increased by a larger amount.

More in detail, general expenses should not be substantially altered; maintenance of way and buildings should be slightly less with electric traction, owing to absence of pounding of reciprocating parts of locomotives, better distribution of weights and absence of deleterious gases.

Owing to absence of smoke and gases, the maintenance of cars, etc., should be moderately less, while the maintenance of motor equipments will probably be less than 50% of the cost of maintaining locomotives for equal service, partially offset by repairs to stations and distributing systems.

Wages should be somewhat less, due partly to the possibility of securing men at lower rates per hour, but more especially to the increased mileage attained, and partly because there is no necessity for waiting about in terminal yards with steam up until called for.

Ordinarily fuel costs will not differ greatly, although they are substantially less with electric traction in favorable cases.

Fuel cost may, in exceptional cases, be slightly reduced by return of the current to the line on down grades and during certain periods of retardation, but ordinarily this is not justified. In special cases, power costs may be reduced by the use of water power, or in other ways, such as the sale of current for light and power in territory occupied by lines electrically operated.

On the whole, total operating costs will not differ greatly, but whether they will be increased or decreased can be determined only by a careful study of each special case. Rarely, if ever, will operat-

Lancashire and Yorkshire Railroad	Liverpool to Southport, England.	23 miles, double track.	"	Alternating current.	7 500 "	4 sub-stations; third rail.	" "
Los Angeles-Redondo Railway	California.	30 miles, double track.	"	"	15 000 "	2 sub-stations; trolley.	" "
Metropolitan District Railway	London, England.	47 miles, double track.	Turbos.	"	11 000 "	Third and fourth rail.	" "
Metropolitan Railway	"	26 miles, double track.	"	"	11 000 "	8 sub-stations; third and fourth rail,	" "
Milan, Varese, Porto Ceresio	Italy.	47-mile route.	Engines.	"	13 000 "	5 sub-stations; third rail.	" "
Mersey Railway	England.	12-mile track.	"	Direct current.	650 "	2 conductor rails.	" "
Manhattan Elevated Railway	New York City.	36.19 miles, double track.	"	Alternating current.	11 000 "	Third rail.	" "
New York, New Haven and Hartford Railroad:							
Nantasket Beach Branch	Massachusetts	7 miles.	"	Direct current.	650 "	" "	" "
Hartford and Berlin	Connecticut.	12.3 "	"	"	650 "	" "	" "
Providence to Warren	Rhode Island.	10 miles, double track.	"	"	650 "	Trolley.	" "
Warren to Fall River	" "	10 miles, single track.	"	"	650 "	"	" "
Warren to Bristol	" "	4 miles, single track.	"	"	650 "	"	" "
North Shore Railroad	California.	.....	.....	.....	.....	.....	.....
North Eastern Railway	Newcastle-on-Tyne, England.	37 miles of route.	Engines.	Alternating current.	5 500 volts.	5 sub-stations; third rail.	Direct current, 600 volts.
Peoria and Pekin Terminal Railway	Illinois.	10 miles, 29½ miles single track.	"	Direct current.	.....	Trolley.	.....
Paris Metropolitan Railway	Paris, France.	24 miles, double track.	"	Alternating current and direct current.	.....	Third rail and sub-stations.	Direct current.
Paris, Orleans Railroad	Paris, France.	14½ miles, double track.	"	Alternating current.	5 500 volts.	Third rail.	Direct current, 550 volts.
Quebec Railway: Quebec to St. Joachim	Canada.	30 miles.	Water Power.	.....	.....	Trolley.	Direct current.
Rome-Frascati	Italy.	26 km.	Engines.	.....	.....	Third rail.	" "
Valtellina Railway:							
Lecco-Chiavenna	"	72 miles.	.....	Alternating current.	20 000 volts.	Three-phase trolley (sectionalized).	Alternating current, 3 000 volts.
Wannseebahn	Berlin, Germany.	11½ miles.	Engines.	Direct current.	750 "	Third rail.	Direct current.
Zermatt-Gornergrat	Switzerland.	9.2 km.	Water Power.	Alternating current.	5 400 "	Three-phase trolley.	Alternating current, 540 volts.

TABLE 4.—Partial List of Electric Railroads Now Operating under Steam-Railroad Conditions.

Name.	Location.	Length.	System.				
			Prime mover.	Generator.	Transmission pressure.	Distribution.	Motors.
Alexandria-Ramleh Railway.	Alexandria, Egypt.	.....	Tosi engines.	Alternating current.	6 500 volts.	.....	.....
Baltimore and Ohio Railway.	Baltimore, Md.	4 miles, double track.	Allis engines.	Direct current.	700 "	Third rail (sectionalized).	Direct current standard.
Berlin Elevated Railway.....	Berlin, Germany.	6.45 miles, double track.	.....	.....	.....	Third rail.	Direct current.
Burgdorf-Thun Railway.....	Switzerland.	25 miles.	Water power.	Alternating current.	16 000 volts.	Double trolley; 750 volts.	Alternating current, 3-phase.
Buffalo and Lockport Railway..	Buffalo, N. Y.	10 miles, single track.	" "	"	20 000 "	Substations; trolley.	Direct current.
Boston Elevated Railway.....	Boston, Mass.	10 miles, double track.	Engines.	Direct current.	550 "	4 stations; third rail.	" "
Brooklyn Elevated Railway..	Brooklyn, N. Y.	67.82 miles.	"	"	550 "	6 power stations; third rail.	" "
Chicago Elevated Lines:							
Metropolitan West Side Railway.....	Chicago, Ill.	37.28-mile track.	Allis engines.	"	650 "	Third rail.	" "
Lake Street Elevated Railway.....	" "	15 miles, double track.	Engines.	"	650 "	" "	" "
South Side Elevated Railway.....	" "	18.62 miles, double track.	"	"	550 "	" "	" "
North Western Elevated Railway.....	" "	25.45-mile track.	"	"	600 "	" "	" "
Union Elevated Railway....	" "	3.96 miles, double track.	"	"	600 "	" "	" "
Central London Railway.....	London, England.	6 miles, double track.	Allis engines.	Alternating current.	5 000 "	4 stations; third rail.	" "
Cincinnati, Georgetown and Portsmouth Railroad.....	Ohio.	40 miles, double track.	Engines.	"	15 000 "	3 sub-stations; trolley.	" "
Düsseldorf to Krefeld.....	Germany.	14 miles, double track.	"	Direct current.	600 "	Bow trolley.	" "
Fayet-Chamonix.....	Savoy, France.	8 miles.	Water power.	"	550 "	Third rail.	" "
Fribourg-Morat Railway.....	Switzerland.	22.4 km.	" "	Alternating current.	8 000 "	2 sub-stations; third rail and trolley.	" "
Great Northern and City Railway.....	London, England.	3½ miles, double track.	Engines.	Direct current.	575 "	Third rail.	" "

New York, New Haven and Hartford Railroad:			
Nantasket Beach Branch...	Electrified steam line.	.....	First steam surface line to adopt third rail, 1895. In 1896 road was extended three miles.
Hartford and Berlin.....	" " "	.....	.....
Providence to Warren.....	" " "	.....	Providence to Fall River, seven stops, in 33 minutes.
Warren to Fall River.....	" " "	.....	.....
Warren to Bristol.....	" " "	.....	.....
North Shore Railroad.....	.....	.....	1903, North Pacific Coast Railroad began to electrify several miles of steam road.
North Eastern Railway.....	Electrified steam.	.....	Power purchased.
Peoria and Pekin Terminal Railway	.....	.....	Mixed electric and steam service.
Paris Metropolitan Railway	Tunnel and overhead.	2-minute service.	Estimated cost when complete, 60 000 000 francs.
Paris, Orleans Railroad.....	Electrified steam.	.....	Two lines used for electric passenger service and two for steam freight.
Quebec Railway:			
Quebec to St. Joachim.....	" "	.....	In 1899 steam road, rails bonded and trolley wires strung; mixed service of electric and steam; June, 1901, to June, 1902, increase of 86 000 passengers.
Rome-Frascati.....	" "	.....	Power purchased in Rome.
Valtellina Railway:			
Lecco-Chiavenna	" "	10 to 13 passenger trains daily.	Parallel speed, 37½ miles per hour; on cascade, 18½ miles per hour.
Wannseebahn	" "	.....	Weight of 10-car train, 193 tons; 20% saving in operating expenses.
Zermats-Gornergrat.....	Maximum grade, 20%	.....	Speed, 7 km. per hour.

TABLE 4.—Partial List of Electric Railroads Now Operating under Steam-Railroad Conditions—(*Continued*).

Name.	Construction.	Service.	Remarks.
Alexandria-Ramleh Railway	.....	10-minute schedule.	Population served, 320 000.
Baltimore and Ohio Railway	Tunnel, heavy track.	Irregular.	Locomotives haul ordinary passenger trains through tunnel.
Berlin Elevated Railway	Elevated and underground.	.....	.....
Burgdorf-Thun Railway	Ordinary, 2½% grades.	Infrequent.	Cost equipment, $200 000; maximum speed, 22½ miles per hour.
Buffalo and Lockport Railway	" level and straight.	Half-hourly.	Niagara power purchased; also has freight locomotives.
Boston Elevated Railway	Elevated and underground.	2 to 5 minute-headway.	Maximum speed, 46 miles per hour; maximum grade, 8%.
Brooklyn Elevated Railway	Elevated.	2 to 5 minute-headway.	.....
Chicago Elevated Lines:			
Metropolitan West Side Railway	Elevated.	Frequent.	Cost of road and equipment, $26 018 670.
Lake Street Elevated Railway	"	"	" " " " " $15 557 284.
South Side Elevated Railway	"	"	" " " " " $11 787 044.
North Western Elevated Railway	"	"	.....
Union Elevated Railway	"	"	.....
Central London Railway	Tunnel.	2½-minute headway.	Total indebtedness, $18 316 005.
Cincinnati, Georgetown and Portsmouth Railroad	Steam road rebuilt.	.....	Heavy freight traffic; first year, 25% increase in takings; passenger fares halved, cut from 3 to 1½ cents per mile.
Düsseldorf to Krefeld	.....	.....	.....
Fayet-Chamonix	Continuation of Paris, Lyons and Mediterranean Ry.	.....	Five motor cars to train; weight of train, with 120 passengers, is 120 tons; maximum grade, 9%; speed, 8 miles per hour.
Fribourg-Morat Railway	.....	.....	Speed of 70-ton train, 14½ miles per hour on 3% grade; 22 miles per hour on level.
Great Northern and City Railway	Tunnel.	3-minute service.	Two separate tunnels, 16 ft. diameter.
Lancashire and Yorkshire Railroad	Electrified steam line.	10 and 20-minute service.	.....
Los Angeles - Redondo Railway	Narrow-gauge steam track, electrified 1903.	.....	Considerable freight traffic.
Metropolitan District Railway	Being converted.	.....	.....
Metropolitan Railway	" "	.....	.....
Milan, Varese, Porto Ceresio	Electrified steam road.	Frequent.	Traffic enormously increased since electrification in 1901.
Mersey Railway	Tunnel and surface road.	3-minute service.	.....
Manhattan Elevated Railway	Elevated.	.....	.....

ing costs be reduced sufficiently to cover interests on the additional investments required, the expected gain from conversion being from increased receipts.

The relative importance of the different items entering into operating costs may be better appreciated by some specific figures.

For 1903, the total expenses of the Pennsylvania Division of the Pennsylvania Railroad were $47 722 082.00, of which

Locomotive repairs amounted to.....	$3 886 860.00
Locomotive fuel.....	4 716 485.00
Locomotive labor.....	4 154 057.00

It is thus clear that each of these three items approximates 10% of the total operating expenses, so that they are about equally important. For reasons given in the body of this paper, it seems probable that saving in locomotive repairs and locomotive wages is likely at times to exceed saving in fuel, although the latter has frequently received nearly all the attention in discussions.

4.—Reliability and Safety.—With thoroughly good equipment, there should be little difference between the two systems; but, with inferior installations, electric equipment will suffer by comparison from somewhat greater chances of interruption to service and increased fire risks, which will, however, be offset, partially at least, by there being no steam or smoke to obscure signals.

In 1895, the Manhattan Elevated Railway made gross earnings of $9 731 213, and net earnings of $3 524 939. In 1901, the gross earnings were $10 253 271, and the net earnings, $4 132 016. In no one of the intervening six years were the net earnings so large, the average being about $3 100 000. For the year ending June 30th, 1904, the gross receipts are reported to have been $14 529 188, and the net earnings, $7 811 462. For the seven years before the commencement of electrical operation, the net earnings were largest in the first of these seven years (1895), and, during this whole period, the average annual gross earnings were practically constant. Consequently, the large increase in both gross and net earnings must be due almost entirely to electrical equipment. The increase in net earnings approximates 23% on the cost of the electrical equipment.

5.—Available Systems of Electrical Equipment.—In nearly all

cases where electrical conversion is justified, direct-current motors alone deserve serious consideration. These should be supplied from direct-current generators, for compact systems operating within a radius of perhaps six miles from the generating station. For greater distances, the current should be supplied from alternating generators through rotary transformers.

If single-phase motors are as well developed as the manufacturing companies claim, they merit consideration where an infrequent service is operated, especially if at considerable distances from the power station. Assuming that accounts of the present development of the single-phase system are not too optimistic, three-phase or other systems will have practically no status in future conversion studies.

6.—Probable Developments.—Within a few years, the New York Central and Pennsylvania Railroads will have useful data from their New York City installations. It seems probable that their suburban services will be gradually extended, as well as that of the New York, New Haven and Hartford Railroad. Having tunnels in Washington, Baltimore and Philadelphia, and crowded terminals in the latter cities, it seems reasonably probable that the electric service of the Pennsylvania Railroad will ultimately be extended to Washington, and be made to include its suburban business from Philadelphia. Before that time, however, other suburban steam roads will probably be equipped electrically from such cities as Chicago, Philadelphia, New York, and some smaller cities.

Within a few years a considerable number of suburban lines in and about London, Paris, Berlin and the smaller European cities should be converted to electrical operation. Some interurban steam roads are also likely to undergo conversion, even where traffic is now light, as on the Italian roads previously mentioned, provided a considerable increase in gross passenger earnings is likely to result.

Other than these, the cases of electrical conversion are likely to be rare, justified only by exceptional circumstances.

Table 4 is a partial list of electric railroads now operating under steam-railroad conditions.

The conversion of main trunk lines and freight roads does not deserve serious consideration, except in rare instances, where in-

creased capacity is urgently needed and not otherwise attainable at reasonable cost, or if operating through frequent or long tunnels.

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Paper No. 61.

THE SUBSTITUTION OF ELECTRICITY FOR STEAM AS A MOTIVE POWER.

By Alexander Siemens, M. Inst. C. E.

In Silliman's *American Journal of Science and Arts*, July, 1831, an account appears of an electro-magnetic engine with automatic pole-changer, which had been devised and constructed by that distinguished American physicist, Joseph Henry, who, therefore, may be regarded as the pioneer in the use of electricity as a motive power.

A few years later, in 1835, Professor Moritz Hermann von Jacoby, then at Dorpat University, published a pamphlet, "Mémoire sur l'Application d'Électro-Magnétisme au Mouvement des Machines," in which he discusses the possibility of utilising magneto-electric machines for industrial purposes. Shortly afterward he was called to St. Petersburg, and there he placed a magneto-electric machine in a boat and went about with it on the Neva.

In spite of this early beginning, there was not much progress in this branch of electrical industry, as the supply of electricity depended either upon primary batteries or machines with permanent magnets. Both these sources were too expensive for commercial work, and the application of electricity as a motive power remained a laboratory experiment until the dynamo-electric machine

had been invented and made practicable by the construction of the ring and drum armatures.

Among the first who substituted electricity for steam as a motive power was Lord Armstrong, who utilised a small stream on his estate to drive a dynamo, and the electricity was utilised in daytime for driving motors in a small workshop and at night for lighting the house.

About the same time Sir William Siemens carried out a similar installation at his country place, near Tunbridge Wells, where he utilised the boiler, erected for heating the greenhouses, to supply steam to a Tangye engine driving a dynamo, and the electricity was used to work motors for pumping, sawing and various other purposes.

In 1877 Sir William Siemens suggested, in his Presidential Address to the Iron and Steel Institute, the utilisation of water-falls for the production of electricity which was to be distributed over large areas, and he illustrated his proposition by sketching a scheme for the water-power then running to waste at Niagara. Such a scheme was, however, at that time beyond the resources of the industry, which in the following years developed principally the application of electricity for lighting purposes..

It soon became evident that the cheapest way of supplying electricity was to follow the example of the gas and water supply by erecting central stations in each district, and the most modern development of this principle is found in the schemes for erecting huge generating plants either near water-falls or near coalpits, according to the motive power selected, which supply electricity for all purposes for miles around.

When these central stations were once established the necessity of utilising the machinery during the time it was not required for lighting made itself felt, especially as the influence of the load factor on the cost of the current is greater than that of any of the items of current expenditure.

This load factor, *viz.*, the proportion which the units sold bear to the total possible output for twenty-four hours per day all the year round, varies inversely with the share each unit sold has to bear of the standing charges, such as interest on capital, administration expenses and all other outgoings which do not vary in direct proportion to the output.

In order to increase the load factor, the lighting companies have encouraged the utilisation of electricity for other than lighting purposes, especially as motive power, and, gradually, electric motors, have supplanted steam engines in a great many instances, even in cases where no public supply of electricity is available.

When, for example, motive power in a factory is required in a number of places, at a distance from each other, it is very often more advantageous to construct a small central station for supplying electricity and to furnish power by means of electric motors, than to provide a number of small steam engines for that purpose. A shipyard is a very good illustration of such an application of electricity, all the more as the facility with which electric motors are moved gives them a decided advantage over steam engines in that industry. This is particularly so in the case of cranes or travellers, either in shops or on quays. In fact, with the spread of power-stations, even most factories will depend for their motive power on a public supply of electricity.

No better example of this tendency could be given than the industrial center which has formed round the power-station at Niagara Falls, but the same substitution of electricity for steam is going on in the United Kingdom, especially within the sphere of the various power-stations that have been recently established.

In another field electric motors have, as yet, not met with the appreciation they deserve, and that is on board ship, where all the auxiliary machinery outside the engine and boiler-rooms should be driven by electric motors. It is true that a great deal has already been accomplished in this respect, and instances can be found on various ships of every one of the auxiliary machines being driven by an electric motor; still, much remains to be done before they will be used to the extent that it is profitable to do so.

Ever since the first electric tram line was built in the Industrial Exhibition at Berlin in 1879, the possibility of using electricity as motive power on railways has been discussed, and it may be claimed that for suburban traffic the superiority of electric motors over steam locomotives has been firmly established.

Such lines have been successfully in operation for some years near Milan and in other parts of Northern Italy, where the water-power of the Alps could be utilised, others have been started in

Switzerland, Germany and France, while in the United Kingdom, the North Eastern Railway Company works its suburban lines near Newcastle by electricity, and the Lancashire and Yorkshire runs electric trains between Liverpool and Southport, and in London the conversion of the Metropolitan and Metropolitan District Railways is in active progress.

Naturally, the introduction of electric motors for working long-distance traffic has received considerable attention, and almost from the first the idea of accelerating the service was connected with that suggestion. A first attempt to solve the problem was made by M. Heilmann, who did not exactly substitute electricity for steam as a motive power, but placed a steam-driven generating plant on his locomotive to supply current to the electric motors which propelled the vehicle. Such locomotives were used for some time to work long-distance traffic; their use, however, has not been extended, although their introduction would not require any capital expenditure for altering the permanent way, or for the erection of central stations for generating electricity.

When secondary batteries were first introduced to public notice the promoters suggested constructing an electric locomotive which should carry its supply of electric energy in secondary batteries, but this idea was never carried out, as the weight of the cells required for a long journey is far too great, at least as long as the present form of accumulators has to be used. For the same reason it would be economically impossible to replace the propelling machinery of steamships by electric motors supplied with current from secondary batteries, in all cases where the batteries cannot be frequently recharged.

Judging by these failures, the way to introduce electric motors on main lines appears to be indicated by the success of tram lines and suburban railways. In this direction experiments were carried out by Siemens and Halske, first at their own works and later on an experimental line near Gross Lichterfelde, but the shortness of the line prevented their making much progress, and they applied to the German Government for permission to equip a suitable length of the Government railways.

During the negotiations with the Government a powerful syndicate was formed for carrying out the experiments on a suitable

scale, and the results obtained on the experimental line between Marienfelde and Zossen have been officially stated by the syndicate in three yearly reports. The line is the property of the War Office, and was built for slow goods traffic. It is about 30 km. long, almost level and has no curves with a radius less than 2 000 m.

In 1901 the first set of experiments were carried out, which proved that the existing permanent way was unsuitable for any speeds exceeding 120 km. (75 miles) per hr. The next year was occupied by further preliminary investigations, and it was only in 1903, after the permanent way had been relaid in a manner equal to the construction adopted on the first-class main lines of the German Government, that the real high-speed runs could be attempted.

For the purpose of these experiments two cars were built by v. d. Zuypen and Charlier, of Cologne, and their electrical equipment was supplied by the Allgemeine Elektricitäts-Gesellschaft and by Siemens and Halske, respectively, while the necessary current was supplied by the Berliner Elektricitäts Werke, at varying voltages, up to 14 000 volts. Each car carried transformers to reduce this voltage to the working pressure of its motors, and it was equipped with all the necessary apparatus for measuring and regulating all the various forces coming into play during the running.

In addition, Siemens and Halske supplied the electrical equipment of a locomotive, also built by v. d. Zuypen and Charlier, in which the high-tension current was supplied direct to the motors without the intervention of transformers.

The two cars, as well as the locomotive, were successfully tried at various speeds, either running alone or drawing a train, and a very complete series of observations were taken during each run, which were set out in detail in the official reports.

Owing to various circumstances the experiments will probably not be resumed this year, although the syndicate intend to resume them in the near future, but the conclusions arrived at up to the present may be summarized as follows:

1.—Permanent way, constructed in accordance with the standard specification for first-class main lines of the German Government Railways, is sufficient for a line on which electric trains run at a speed of 200

km. (125 miles) per hr., but the radius of any curve should not be less than 2 000 m. (100 chains).

2.—The collector, devised by Siemens and Halske during their preliminary experiments, and modified according to the experience gained at Zossen, is well adapted for conveying the necessary electrical energy at high tension and at the highest speeds from the fixed conductors to the cars.

3.—The construction of the fixed conductor along the line as devised for Gross Lichterfelde, has proved its efficiency at Zossen.

4.—The successful running of the locomotive has demonstrated that high-tension currents can be used direct, without the intervention of transformers.

These results prove that technically it is possible to work trains by electricity on main lines, even at speeds greatly exceeding those of the present express trains. In their last report the syndicate publish two projects for such a line between Berlin and Hamburg, according to which such a railway should prove a success also commercially. As already stated further trials are contemplated to determine the most suitable equipment for the cars and to experiment with modifications of the general arrangements.

While the problem has not yet been completely worked out, electric motors are accepted without question in the mining industry as decidedly superior to steam engines for underground work, and they will replace them also for working the main winding-drums, as soon as the qualities of electric motors are better appreciated, which have, in the various instances already given, made the change from steam power advantageous for the user.

Comparing generally the working of steam engines with electric motors connected to a permanent source of supply, the features in favour of the latter may be summarized as follows:

1.—The most suitable size of conductors to convey the current to an electric motor can be accurately determined beforehand, with the certainty that the loss of energy calculated upon will not be exceeded.

Such conductors are generally in the form of

flexible leads, which are easily handled and readily adapted to their surroundings which they will not affect when properly selected and fitted, nor do they give rise to waste products that have to be separately disposed of.

2.—Owing to the simplicity of their construction and the absence of reciprocating parts, much less supervision is required for electric motors than for steam engines.

3.—For the same reasons the vibration caused by the working of electric motors is reduced to a minimum, and in consequence, heavy foundations can be dispensed with.

4.—This again makes it possible to shift motors readily from one position to another especially as the conductors in the shape of "wandering leads" are specially adapted for such purposes.

5.—Lastly, an electric motor connected to a permanent source of supply, is always ready to commence working, while a steam engine requires warming up, and very often, if the engine has a separate boiler, steam has to be raised specially, causing great delay in starting.

Against these advantages due account has to be taken:

1.—Of the losses, caused by the double transformation of energy; and

2.—Of the interest on the additional capital expenditure.

When the current is obtained from a public supply both these items are partly represented by its price.

It will be noticed that by utilising electric motors it is possible greatly to diminish current expenses, while the interest on capital outlay is increased and with it the charges for depreciation, so that the most economical result may be expected when the electric motors can be kept working for long hours. In other words a high load factor is as advantageous with motors as with generators to obtain a satisfactory return for the change from steam power to electric motors. This makes it possible in many cases to decide without

difficulty whether it is advisable to substitute electric motors for steam engines, but there are also instances where electric motors are cheaper although the load factor is low, and this has to be determined by carefully considering in each case all the possibilities for providing power.

Generally speaking, the experience gained hitherto makes it clear that in certain cases, notably for the propelling of ships, it is not likely that electric motors will ever replace steam engines, on the other hand it appears certain that the days of small, scattered, steam engines are over, whether they have separate boilers, or are fed by long steam pipes from a nest of boilers.

Electric motors have not only replaced steam engines, but they have been adopted for a great many purposes where steam engines have either never been used or have proved to be unsuitable; these cases are not, however, germane to the subject set for this paper, nor would it be appropriate on this occasion to discuss the relative merits of alternate and continuous-current motors beyond referring to the generally accepted opinion, that continuous-current motors are most suitable in cases where the speed of running has to be varied often and to a great extent, while alternate-current motors are most efficient in cases where long runs at constant speed are required.

The conclusion to be drawn from the consideration of the relative position which steam engines and electric motors occupy at present, appears to be that it is more correct to regard the one as the supplement of the other rather than to expect a complete substitution of electricity for steam as a motive power.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

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DISCUSSION ON

THE SUBSTITUTION OF ELECTRICITY FOR STEAM AS A MOTIVE POWER.

By Messrs. Gustav Schimpff, L. B. Stillwell and J. G. White.

Mr. Schimpff

Gustav Schimpff, Esq., Altona, Germany.* (By letter.)—It is difficult to prophesy, but it is not absolutely certain that, in the near future, electricity will compete with steam in high-speed railroading. However, there is another domain where electricity, as a motive power, will undoubtedly replace steam, *i. e.*, in the field of city and suburban railroading, where there is a great deal of traffic. From a technical and economic standpoint, electricity is specially advantageous for this purpose.

1.—Electrically-driven trains, in which the motive power is divided into a great number of small units, can obtain a better acceleration than trains hauled by a steam locomotive. A steam engine hauling a train of average weight (say, 160 tons) has great difficulty in attaining an acceleration greater than 0.15 m. (6 in.) per sec., while, in electric traction, an acceleration of 0.3 m. (1 ft.) per sec. is a commercial one, and an acceleration of double that amount (0.6 m.) can be reached easily. This means a greater schedule speed and a closer headway for electric trains, because the headway, *i. e.*, the time between two consecutive trains, is dependent on the time which a train spends in the station, between in-coming and out-going signals, and this is made up of the time spent in braking, in stopping and in acceleration. In most cases, the difference in favor of electric transportation will be only a fraction of a minute (say, 30 sec.), but this may be of great value in cases

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Mr. Schimpff. where it is necessary to increase the traffic capacity of a city railroad.

2.—If the height of the car floor permits of placing the motive power entirely under it, it is possible to utilize the total length of the train for the paying load, while, in a steam train, the length of the locomotive is a loss. This, again, increases the capacity of the road if the length of the trains is limited by the length of the platforms, or the location of the switches at the terminals.

3.—Electric trains, with a compartment for the motorman at each end, avoid switching on stub-end terminals, therefore the area of terminal stations may be diminished, and a better disposition of tracks and platforms may be attained.

4.—If the electric train consists of motor cars only, and a system of train control is used, it is possible to vary the length of the train in accordance with the density of the traffic during the different hours of the day. With steam traction, this is nearly impossible, because changing the number of coaches in the train at the terminal necessitates a good deal of switching, for which room and time are generally lacking. Therefore it is possible to diminish the number of car-miles run per day on electric traction without decreasing the number of places offered during rush hours. With electric trains, it is easy to obtain in this manner a "coefficient of occupancy of places, *i. e.*, $\frac{\text{number of occupied places}}{\text{number of offered places}}$, of 30% as the average for the day, while, with steam traction, it is impossible to reach a better result than 25%, supposing the headway to be kept constant during the greater part of the day. There are a number of railroad companies which vary the headway between trains according to the traffic at the different hours of the day; but that is very poor practice, as it compels the traveler to consult a time-table.

5.—With electric traction, the amount of wages paid to the train crew will be far less than with steam practice. The minimum number of men per train is two with electric traction and three (locomotive engineer, fireman and conductor) with steam traction. Motormen receive lower wages than locomotive engineers, and their total number will be less, because it is not necessary to care for the "lay over" at terminals and for switching. The total expenditure for wages will not be more than one-half as much as with steam practice.

6.—The total cost of electric traction compared with steam is dependent on a number of factors which vary with the local conditions of the line. If coal is to be used as fuel in the power-house, the total cost of the motive power for the electrical plant, including interest and depreciation, is undoubtedly somewhat higher. The difference is dependent principally on the load factor. If the latter

is high, *i. e.*, if the traffic on the line is nearly constant during the week and during the year, the difference will be almost nothing; if the load factor is low, because Sunday and summer traffic is considerably larger than the average traffic, the interest and depreciation of the power plant enlarge the cost of electric power considerably, while, on steam-driven lines which form a part of a greater system, it is generally possible to make use of the coaches and locomotives, not needed on week-days and in winter, on other lines. The usual steam heating of railroad coaches costs only about one-third as much as electric heating, even if the cost of fuel alone is counted in both cases. There is no difference at all in the expense of lighting the cars. Finally, the only saving which is possible in electric traction is in the wages of the train crew. But, on the other hand, electric traction attracts the traffic and increases the income of the company, if it is possible to augment the density of traffic along the line. Mr. Schimpff.

On city and suburban lines, there is the question as to whether it will pay to equip electrically a number of local lines (railways of the second order) on which usually only a small number of "mixed" trains (say from three to five in each direction) are run. Here, the number of travelers will increase considerably, if, instead of a few trains, a motor car is run every hour (as on American interurban railways), and the cost of energy can be kept down if water power is available, or gas-motor plants can be erected near large turf moors. This brings up the problem of a method of producing gas from peat.

As electrical engineers have succeeded in constructing single-phase alternating-current motors, there is a question as to whether an alternating or a direct current is the better adapted to replace steam. This question cannot be answered generally, because a number of local conditions may be favorable to either system, if a certain line is under consideration. In alternating-current practice, the working conductors, owing to the higher tension, are generally in the form of overhead wires; in direct-current practice, it is necessary to choose the third rail as a conductor, if heavy traction is demanded. Railway engineers generally prefer overhead wires, because the third rail makes the maintenance of way more difficult and expensive. On highway crossings and at switches, the third rail must be omitted entirely. But, if there are a number of bridges over the railroad, or if the road runs partially in tunnels, a number of difficulties arise in the placing of overhead wires which are to carry high-tension currents. On the other hand, an overhead trolley with sliding contacts seems to be a little better adapted for higher speeds than the third rail.

It may be concluded that in city lines it is often preferable to

Mr. Schimpff. retain direct current, while in open country alternating current may be adopted.

If local conditions do not oblige the engineer to choose either the overhead wire or the third rail, it is a question of economy to decide between the two systems of current collection. If the length of the line exceeds 10 km. (6 miles), it will be necessary, in regard to first cost, to adopt polyphase transmission in connection with direct-current distribution. If the cost per kilowatt-hour is 6 pfennige (1.4 cents) measured at the bus-bars of the power-house, it will amount to 9 pfennige (2.1 cents) at the bus-bars of the sub-stations, where alternating current is transformed into direct current. The difference (3 pfennige) is caused principally by wages at the sub-station, interest, and depreciation of the machinery, and can be avoided if alternating current is applied directly to the motors. On the other hand, alternating-current equipments are generally from 10 to 20% heavier than direct-current equipments, not including the transformer on the car, which is necessary if the voltage of the line is high. This increases the consumption of watt-hours per car-mile on alternating-current equipments.

To get a correct statement of the relative merits of both direct and alternating-current collection, the Prussian State Railways have equipped with the third rail and direct-current motors, and the line from Berlin to Gross-Lichterfelde, 9 km. (5.6 miles) in length, was equipped with the third rail and direct-current motors, and the line from Nieder-Schoeneweide to Spindlersfeld, 4.1 km. (2.5 miles) long, was equipped with overhead wires for 6 000 volts of alternating current, and single-phase motors of the Union (Winter-Eichberg) type. According to the financial results of these two experimental lines, the Prussian State Railways have recently decided to equip the city and suburban system of Hamburg, a line 27.5 km. (17 miles) in length, with alternating current of the same system as applied to the Spindlersfeld line. It is expected that this line will be operated in about two years.

Mr. Stillwell. L. B. Stillwell, M. Am. Soc. C. E., New York City.—The speaker believes that Mr. White's paper will be approved by the average judgment of American electrical engineers as summarizing with substantial accuracy the state of the art of applied electricity as regards its possible use as a substitute for steam as motive power in traction work, except that the paper places too little emphasis, perhaps, upon advantages of alternating-current motors in cases where any considerable distance is involved. Mr. White is an extremely busy man and is entitled to the thanks of the Congress for having taken time to prepare so comprehensive and interesting a paper. There are, however, a number of points in respect to which the speaker believes Mr. White's presentation can be emphasized to advantage and in some instances perhaps modified.

Mr. White's statement of the question, upon the answer to which Mr. White says that the advisability of substituting electric traction for steam will depend, would be improved by using the word "maintenance" or the word "up-keep" in place of "depreciation." It appears obvious that Mr. White did not intend to use the word depreciation. Machinery that is maintained remains in a condition of excellence equivalent to its condition when first placed in service; the cost of keeping it in such condition is the maintenance or, as our English friends more frequently call it, the up-keep. Depreciation, as the speaker understands the use of the term, designates an amount which should be set aside annually in every undertaking of the kind under discussion for the possible, perhaps probable, renewal of the entire plant at some future date, that date being fixed by reference, not only to the existing state of the art, but also to the probability or possibility of the invention of something that will supersede the apparatus installed. The terms, depreciation and amortization, are properly synonymous, but neither should be confounded with maintenance. Mr. Stillwell.

With reference to Mr. White's statement that all engineers who have studied the problem carefully agree that ordinary trunk-line steam railways, under present conditions, belong unquestionably to the class for which electric traction is not suitable, the speaker thinks the phrase "ordinary trunk-line steam railways" very indefinite; perhaps this is necessarily so, but he suggests that a closer approximation might be arrived at by saying that Class *B*, as designated by Mr. White, includes all railways upon which the traffic per day per mile of double track does not exceed 10 000 ton-miles. Possibly, to be entirely safe it might be well to take the figure, 15 000 ton-miles per day, but the speaker is of the opinion that in cases where the traffic per day per mile of double track exceeds 10 000 ton-miles, the question of application of electricity is worthy of consideration. In the case of single-track railways, the figure chosen as representing the minimum traffic which would justify consideration of electric traction should be from 25 to 50% higher per mile of track than in the case of double-track railways.

What Mr. White says under the heading "General Comfort of Passengers" is most timely and deserves to be emphasized. It is a fact that the managers and engineers of steam railways in the United States do not recognize sufficiently the importance of the superior cleanliness, ventilation, lighting and heating of electrically-propelled passenger cars. Upon the part of some of these gentlemen, there is too much of a disposition to believe that the public must travel, must pay the established rates, and must continue to submit to existing discomforts in traveling for the reason that in many cases there is no alternative but to remain at home. The trolley lines have done a great deal in the way of educating people

Mr. Stillwell. upon this subject, by developing in many cases enormous traffic upon lines paralleling steam railways.

In connection with cleanliness, there is another fact which might be mentioned, *viz.*, that the advantages of electric traction, in this respect, are great, when considered from the standpoint of citizens of towns traversed by the railways. There is a strong sentiment springing up in many cities in favor of compelling steam railways to use smokeless fuel within the city limits. There can be no doubt that, were it possible to determine the aggregate damage caused by the smoke of steam locomotives in passing through the cities of the United States, it could be shown that the monetary equivalent of this damage to clothing, house furnishings, etc., would pay a handsome return upon the entire capitalization required to electrify every mile of railway existing within the limits of these cities.

In discussing the question of safety, Mr. White does not specifically call attention to the fact that an increase in speed in itself has a two-fold value: (1) in making it possible to do a given business with rolling-stock equipment decreased in proportion to the increase in speed; and (2) by reason of the fact that the public is enormously attracted by the higher speed. Experience of the Manhattan Elevated Railway in New York since the adoption of electric traction, as a result of which average speed of local trains has been increased from about 12 to 15 miles per hour, has demonstrated that the increase in speed has resulted in a marked increase of traffic. The substitution of an average speed of 15 miles per hour for an average speed of 12 miles per hour also means, of course, that four cars would now do the work formerly requiring five.

The speaker calls attention to Mr. White's statement in respect to power required in operation of trains upon the Manhattan Elevated Railway. He has not been informed as to the source of Mr. White's information, but is able to say that the figures given are in error. The average consumption of power for traction purposes in operating trains varying in length from three to seven cars, at speeds averaging, in local service, 15 miles per hour, including stops, and, in express service, about 22 miles per hour, including stops, is about 100 watt-hours per ton-mile measured at the power-house, and, by calculation, approximately 80 watt-hours per ton-mile, as delivered to the trains. Including lights in cars and in substations, the average figures for summer months are, at the power-house, 102 watt-hours per ton-mile, and, as delivered to trains, 82 watt-hours per ton-mile.

Mr. White states that on some new lines a saving can be made by reduction of curve radius and increase of maximum grades. In the speaker's opinion, the advantages of electric traction in respect to ability to surmount with safety grades prohibitive in steam service

deserve to be emphasized. It is well-known that trolley cars in many places are in commercial use upon grades of 8 and even 10%, and the multiple-unit system of train equipment, by utilizing, if necessary, the entire weight of the train to obtain necessary adhesion, makes it possible to operate trains over similar grades, provided adequate precautions are taken to hold the train in running down grade. In many sections of the United States, a cut-off which would effect a great saving would be practicable, were grades of even 5 or 6% considered permissible. The speaker believes that electric traction makes it perfectly safe not only to climb such grades, but also to descend them, since it affords an opportunity to supplement the air-brake equipment by a magnetic track brake of the type in which the shoe that bears upon the track is magnetically drawn down to the track rail when in action, so that its effect is to increase the effective braking weight of the train. This type of brake, which has been developed and is extensively used in connection with trolley cars, when applied to cars or trains using standard air-brake equipment, unlike most types of track brake, in no way decreases the effectiveness of that equipment, but, on the contrary, tends to increase it. The magnetic track brake in itself is very powerful, and experience has shown that where this brake is used in connection with standard air brakes, trains running at a given speed may be brought to a stop within a materially shorter distance than is possible if the air brake alone be used. The magnetic track brake, moreover, is a most valuable safeguard in cases where the track rails are liable to be covered by snow or sleet, since the brake shoes cut through to the track, and the danger of skidding, which exists under certain conditions where air-brake equipment alone is used, is practically eliminated. By using the multiple-unit system of motive-power equipment and the magnetic track brake in connection with air brakes, it would be safe to operate heavy trains over grades of not less than 6%, and possibly over grades considerably exceeding that amount. The practical effect of such a possibility in laying out a line of railway through mountainous country is obvious. As suggestive of such possibilities, he instances the Wilkesbarre and Hazleton Railway which, from the outstart, had been constructed under plans contemplating electric traction. This railway competed with a branch of the Pennsylvania System and with the Lehigh Valley Railway, in a mountainous country, where the steam roads in general limited their gradient to a maximum of 2 per cent. The electric railway, using a grade of 3%, was able to find a line connecting the two cities named by a run of less than 30 miles, as compared with 49.6 miles in the case of one of the competing steam lines and 50.4 miles in the case of the other, the distance as the crow flies being 21 miles. The electric passenger

Mr. Stillwell.

Mr Stillwell. cars, weighing 84 000 lb. without passengers, climb a 3% grade at speeds materially exceeding the speed of the average steam passenger train in climbing the 2% grades adopted by the competing lines. In a test made about a year ago, one of these cars, hauling a 70 000-lb. standard railway coach as a trailer, climbed the 3% grade at speeds varying from 34 to 28 miles per hour, the speed falling off as the potential decreased with increase of distance from the source of power supply.

In discussing the cost of central station and distribution system, Mr. White's estimate, *viz.*, "about $130 to $150 per kw. of capacity, including buildings and land," probably refers to stations of moderate size only. Very large stations can be constructed for less cost per kilowatt, and plants of from 40 000 to 50 000 kw. can be built complete for from $110 to $120 per kw. It is to be noted also that in cases where the traffic to be taken care of is not uniform, but, as is usual in intra-urban and suburban service, is characterized by a morning and an evening peak, the power plant, if purchased under proper specifications, would be able during the period of such peak loads to supply energy exceeding the normal rated capacity of the plant by from 25 to 50 per cent. This of course in such instances would very materially reduce the cost per maximum kilowatt output.

Referring to Mr. White's statement that the selling prices of steam turbines would probably be reduced in the future, the speaker has recently obtained from leading manufacturers comprehensive data relative to the comparative weights of turbine-driven dynamo units and units of similar output driven by reciprocating engines, and the difference in weight of the two types is extremely marked. Taking into account the difference in amount of material required and also the relative cost of labor and tools involved in the contrasted types of construction, there is every reason to believe that in the near future lower prices of the turbine units may be expected.

Referring to the desirability of protecting the contact rail against weather as well as against accidental contact, Mr. White states that the trouble "might possibly be met by some form of protected third rail." A protected third-rail system has been in successful use on the Wilkesbarre and Hazleton Railway for more than two years and, although doubtless susceptible of further improvement, appears to be effective. It consists essentially of a plank, 6½ in. wide and 2 in. thick, carried horizontally above the contact rail. It is supported upon wooden posts which are clamped to the rail. During the winter of 1903-04, which was abnormally severe, operation of the road was interfered with by snow and sleet to a slight degree only, the aggregate delays to cars being less than two hours. In the opinion of the speaker, this system may be considered an effective protection against snow and sleet. It involves

the use of a shoe of a type differing from that hitherto generally used. The type is due to Mr. W. B. Potter, of the General Electric Company, and has been described in various technical publications. As used in Hazleton, it has been modified in detail and is regarded by the officials of the operating corporation as highly successful. In this connection, the fact that a collecting shoe and rail guard of the type referred to have been adopted by the Interborough Rapid Transit Company for the operation of the new subway in New York may be of interest. In this instance, the width of the plank guard has been increased to 8½ in., the method of carrying it remaining substantially the same as on the Hazleton road. The design of the collecting shoe has been considerably modified in detail, but the type is preserved. Springs are used to preserve contact between the shoe and the rail, the shoe itself being comparatively light. In the opinion of the speaker, which opinion is based upon experience in actual operation and upon numerous tests, such a shoe is decidedly superior to the usual form of drag-link gravity shoe, particularly at high speed. Mr. Stillwell.

In reference to sectionalizing the third rail, while this has been strongly advocated by many who have given it more or less thought, the speaker believes that it is far better to guard the rail and sectionalize it to a very limited extent only, the interference with train movement that is liable to result from the use of any automatic sectionalizing system thus far proposed being a most serious consideration.

In discussing operating costs and under the specific heading "Maintenance of Way," Mr. White states that

"Maintenance of way remains practically constant in either case, although there may possibly be some slight saving in favor of electric traction, due to the lighter trains and better distribution of weight."

In the opinion of the speaker, that statement is not entirely fair to electric traction. He believes there are many cases where the saving in cost of maintaining the permanent way would be material. Of course in substituting electric traction for steam, an increase of speed becomes possible and generally speaking would be promptly utilized. This increase of speed would tend to increase cost of maintenance, but there can be no doubt that at a given speed electric traction possesses substantial advantage, in respect to less wear and tear of track and bridges, by reason of the elimination of the unbalanced parts of the locomotive and by distributing weight of motive-power equipment throughout the train instead of localizing it in a locomotive and increasing it by dead weight useful only in securing adhesion. The speaker does not mean to imply that permanent way should be made lighter or less durable than at present; on the contrary, he believes none of it to be too good as it is,

Mr. Stillwell. but he does wish to be understood in saying that the substitution of electric traction for steam may be expected to reduce cost of permanent way for given speed and traffic.

Another point in which the speaker finds his views at variance with those of Mr. White relates to cost of fuel. The question to be decided is not the relative amounts of fuel consumed by a locomotive drawing a train between stations, on the one hand, and fuel used by an electric power plant generating and transmitting energy to a similar train operating between stations. The question is what would be the aggregate amounts of fuel consumed in the operation of a given railway using, on the one hand, steam locomotives and, on the other hand, electric traction. Obviously, the stand-by losses would be important in both cases and in the opinion of the speaker they would be much less in the latter case than in the former. Moreover he believes that the average steam locomotive in the United States burns more coal per brake horse power than would be inferred from Mr. White's statement. Doubtless there are some engineers whose experience in operating steam railways would enable them to supply correct figures, but as corroborating his own conclusions which are based upon considerable investigation, the speaker refers to the fact that the distinguished mechanical engineer, Dr. J. C. Bayles, of New York, as the result of careful study of the subject, has reached the conclusion that a fair average figure for steam locomotives is from 15 to 16 lb. per effective horse power hour, this figure including, of course, coal burned in firing and consumed in maintaining steam while standing idle. As contrasted with this figure, attention is called to results obtained in electrical operation of the Manhattan System, in which it has been found by dividing the aggregate amount of coal used during a period, now exceeding a year, by the aggregate electrical output of the power plant measured in kilowatt hours at the switchboard that, including power supplied to auxiliaries, 1 kw-hr. at the switchboard was produced by 2.6 lb. of coal. The efficiency of electric transmission from the switchboard to the third rail is of course calculable with accuracy, and likewise the efficiency of the motor equipment. According to his estimates, the average efficiency from power-house switchboard to tractive effort exerted at the cars slightly exceeds 60%, but assuming 60% to be the correct figure it follows that 1 h. p-hr. in tractive effort is produced by the consumption of less than 3.25 lb. of coal. This, it should be noted, includes all "stand-by" losses at the power house. In the case of smaller plants, it would not be reasonable to expect equally good results, but it is to be noted that in the electrification of railways, now operated by steam, the plants installed for generation and transmission of electricity, generally speaking, would not be small.

Mr. Stillwell.

Again, the speaker thinks Mr. White's estimate of the full-load and average-load efficiencies of the steam and electric plant is too low; probably Mr. White had in mind plants of no great size, as it is certain that in large plants, such as would be needed for operation of any considerable railway service, higher economy can be secured. In the case of the 40 000-kw. plant of the Manhattan Railway Company, the full-load and average-load efficiencies are estimated as in Table 5:

TABLE 5.

	Full-load efficiency.	Average-load efficiency.
Mechanical efficiency of engine	94%	92%
Generators	97.5%	97%
High-pressure transmission lines	98%	99%
Sub-station transformers	98%	97.5%
Rotary converters	97%	96%
Low-tension distribution	90%	97%
Motors, including gears and rheostats	75%	75%
Total efficiencies	57%	60%

The plant referred to produces a kilowatt-hour at the power-house switchboard from 2.6 lb. of coal. This figure covers all the coal used, and about 4% of the power generated is used for the operation of the auxiliaries and does not leave the power house. Under conditions of full load, it appears, therefore, that we obtain at the train, electrically operated, a kilowatt-hour from 4.33 lb. of fuel consumed at the power house, or a horse-power hour for a fraction over 3.23 lb. of fuel. The speaker thinks that he is justified in stating that, in the case of large generating plants, there would be a very material saving in fuel account as a result of the substitution of electric traction for steam. It is difficult to name a definite figure, but it is his present opinion that in the average case where conditions might justify substitution of electricity for steam, the fuel consumed would be reduced to not more than one-half and possibly as low as one-third of the amount required by steam traction. In this connection, it might be well to point out that, in adopting electric traction, railways would place themselves in position to utilize promptly any further developments in internal combustion engines. Some gas engines are now producing a horse-power hour from about 1 lb. of coal. The probability of radical improvement in economy of utilizing fuel energy appears to be much greater in the case of stationary plants than in that of movable engine units adapted to traction purposes.

Referring to Mr. White's statement, that "the steam locomotive

Mr. Stillwell. has a material advantage in being a self-contained unit," the speaker thinks that the addition to permanent-way equipment necessary in using electric traction is the greatest objection to its adoption. For long-distance equipment, the third rail, in his opinion, is inferior to a substantial and well-designed overhead construction. The problems involved in the design of such a construction, adequate and in every way satisfactory under the many varied conditions to be met with in service, are complicated, and engineering opinion, as to what is best, has not yet crystallized. Undoubtedly a satisfactory solution will be found.

The speaker desires to emphasize what Mr. White says in regard to the lessened danger of interruption to traffic existing in the case of electric traction by reason of the fact that with the multiple-unit system the failure of the electric equipment of a single motive-power unit would not materially affect the operation of the train. In the electric operation of the Manhattan Railway it has been found that the total delays per car mile, due to all causes during three months of 1904, were less than 40% of the delays per car mile experienced during the corresponding months of 1901, when steam locomotives were in use. Two-thirds of the cars are equipped with motors and control apparatus which is necessarily very complicated and might be expected reasonably to cause more or less trouble, but in actual service, electric operation has secured the very gratifying results above stated.

There is a specific and important cause of frequent delay to traffic in operation by steam which is not referred to in Mr. White's paper, *viz.*, the failure of the locomotive in cold weather to make steam and therefore to preserve schedule time. Those who travel in our Northern States in winter know how frequently serious interference with traffic is due to this cause. Experience sufficiently justifies the statement that delays in the case of electric traction due to snow and ice may be expected to be practically negligible as compared with delays in steam service caused by cold weather. On the other hand, electric traction will undoubtedly be subjected in summer to annoying delays, due to interruption of power supply caused by lightning. The speaker believes, however, that if precautions known to the art in the erection of overhead lines and the safeguarding of apparatus by automatic devices are duly observed, the power supply to trains can be maintained satisfactorily.

In discussing the relative safety of steam and electric systems, Mr. White states that

"With an electric system, however, it is readily possible to increase safety by controlling the trains automatically by the installation, at the end of each block, of automatic devices for cutting off the current if a train runs past its signal."

Mr. Stillwell.

The speaker does not believe that the method suggested is either effective or desirable. A better method of accomplishing the object in view is to use mechanical devices attached to the track, and arrange to apply the air brakes in case the operator should run his train past the danger signal. This has been done in Boston and is being done in the New York Subway. To cut off power is not effective when the train happens to be running down grade.

Among the rules which Mr. White proposes with a view to minimizing fire risk is one prohibiting the running, from one car to another, of wires carrying heavy currents. The speaker questions the advisability of such a rule. In his opinion, it is not more dangerous *per se* to run, from one car to another, a conductor carrying a heavy current than it is to run such a conductor from one end of a car to the other. To adopt the rule would prevent the use of a train line used to convey power from the collecting shoes of adjacent cars to the motors of a car whose collecting shoes may momentarily fail to make contact with the third rail, as, for example, at a cross-over where the distance between adjacent ends of the third rail is such that the shoes of a single car cannot bridge the gap. This means that the lights in each car will be extinguished as it passes the cross-over, which is inconvenient and objectionable although not dangerous. A more serious objection to the suggested elimination of the train line, however, rests upon the fact that in operation the train line in a considerable degree insures the train movement. Without it trains would be more apt to become disabled. To stop a train at an unexpected point always involves some degree of risk, and to establish a dictum of the kind suggested would be to lay down a rule that might result in incurring a risk greater than that which it aimed to eliminate. Everything practicable should be done to emphasize the necessity of adequately protecting cars against risk by fire from motors, control equipment, or wiring. It is perfectly feasible, however, to secure a degree of safety beyond anything yet attained in steam railway service without limiting the flexibility and certainty in operation of the train equipment.

In recommending that "in tunnels, especially, the system of contact conductors should be divided into short sections," the speaker does not understand Mr. White to recommend what is usually known as a sectional system. A little consideration would make it obvious that the plan of dividing the contact conductor into sections comparable with the length of the train, which plan has been frequently suggested by people who apparently do not appreciate the disadvantages of the resulting complication and consequent interference with traffic, could not be adopted advantageously in dealing with conditions under which trains follow each other at short in-

Mr. Stillwell. tervals, and continuity and regularity of service are of prime importance. In few cases would the arguments in favor of thus sectionalizing the third rail outweigh its disadvantages. In the opinion of the speaker, it is wise to make the sections of contact rail equal in length to the distance between successive sub-stations from which the power supply is derived, thus concentrating automatic switching apparatus in the sub-stations where it will be under the care of skilled attendants. Experience has demonstrated what theoretical considerations have always indicated with sufficient clearness, *viz.*, that the use of automatic circuit-making and circuit-breaking devices, through which power supply must reach successively the short sections of a contact rail, is inadvisable from the standpoint of maintenance of traffic and unnecessary from the standpoint of safety. The speaker suggests that an important precaution which ought to be adopted by every railway using electric equipment is one which, so far as the speaker is aware, has been adopted first by the Manhattan Railway Company in New York, *viz.*, the employment of a high potential test applied to the insulation of the assembled car equipment, including both motors and wiring. It is the practice of the Manhattan Company to apply between copper and ground an alternating potential having a mean value approximating 2 000 volts. This is done in the case of every car turned out of the shop, the equipment of these cars being adapted to operation by continuous current at a potential of 570 volts. The test is applied not only in the case of cars newly equipped, but also to every car before leaving the shops of the company after its annual overhauling. To this practice of testing, the speaker attributes much of the immunity from accident which the Manhattan road has enjoyed, notwithstanding the fact that it employs in its electrical service a large part of its old rolling stock. In the case of these cars, it should be mentioned also that asbestos board has been placed between all electrical apparatus and the woodwork of the car.

It appears to the speaker that Mr. White's statement of the disadvantages of the alternating-current system of transmission cannot be an accurate expression of his opinion. He presumes that Mr. White intended to say that within the transmission distance to which direct current was directly applicable, the losses were easily restricted to 15% when that system was used, and that for greater distances to which the combined alternating and direct-current system would apply, if direct-current motors were to be used, the aggregate average losses would approximate 24 per cent. In the opinion of the speaker, these general approximations are apt to be very misleading, but the figures selected are perhaps fairly representative of average conditions. Obviously, Mr. White had not intended to say that within the distance to which the direct-current

system would be applicable with loss not exceeding 15%, the losses involved by the adoption of the combined alternating and direct-current system would average 24 per cent. Mr. Stillwell.

Referring to Mr. White's statement of the relative advantages of the direct-current system and the three-phase alternating-current system, the speaker thinks that Mr. White's statement is calculated to convey an exaggerated idea of the advantages of the former and the disadvantages of the latter. For example, the very high starting torque of the direct-current motor is referred to as a marked comparative advantage. Undoubtedly the series-wound direct-current motor possesses a high torque, but three-phase motors are also capable of developing a starting torque sufficient to slip the wheels, and beyond this the advantages of increased torque are not obvious. Mr. White also expresses the opinion that the direct-current motor possesses an advantage over properly designed tri-phase motors in respect to ability to carry heavy overloads for short periods. On the contrary, the direct-current motor under conditions of overload finds a limit in its ability to commutate the current, which limit does not exist in the case of a tri-phase motor. Recent tests of tri-phase motors, as constructed by the Ganz Company of Buda-Pesth, have convinced the speaker that they are capable of carrying, in general, heavier overloads than direct-current motors which are fairly comparable in respect to weight and speed.

The speaker also questions the statement that the direct-current motor possesses advantage in respect to cheap and simple construction and light weight. It is a fact that tri-phase motors of American manufacture are heavier than continuous-current motors of the same rating, but there are no inherent properties which compel this condition. Its existence is due in large measure to the fact that the designers of tri-phase motors in America started with the assumption that large clearance between the rotor and the stator was necessary by reason of mechanical considerations and, in basing their design upon this assumption, they incurred material sacrifices in respect to efficiency, power factor and weight. The engineers of the Ganz Company, realizing the great importance of minimizing the clearance, have worked out mechanical bearings which permit the satisfactory use of clearances not exceeding 2 mm., even in the case of railway motors rated at 400 h. p. The speaker has been informed that the weight and cost of tri-phase motors, as furnished by the Ganz Company, does not exceed the weight and cost of comparable direct-current motors produced by the same company. The principal disadvantage of the tri-phase is the fact that it requires two trolley wires; on the other hand, as compared with the direct-current motor in equipping roads of any considerable length, it possesses substantial advantages.

Mr. Stillwell.

As regards disadvantages of the alternating-current system, Mr. White apparently has misread the report of experiments made by the General Electric Company in determining the resistance of the track circuit when direct current was used, and its impedance when alternating current was employed. The fact is that the impedance, in the case of a certain length of track and a frequency of 25 cycles per sec., is found to be 6.55 times the resistance of the same length of track. This does not mean that the track "had a carrying capacity with direct current 6.55 times as great as with alternating current." The observations referred to bear upon the question of potential drop, and the determination of this relation in the contrasted systems of supply does not in itself fix the relation of the proper carrying capacity of the track.

Referring to the fact that tri-phase motors in running down heavy grades and in stopping may be used as generators to restore energy to the supply circuits, Mr. F. N. Waterman has recently made interesting tests of the energy thus returned to the circuits on the Valtellina Line in Italy. A train of seven cars was placed at his disposal, and thorough tests extending over a number of days were made. Of the energy required to lift the train up a grade averaging 1.8%, upwards of 60% was restored to the supply circuits in descending.

In a tender submitted during 1904 by the Ganz Company to the Austrian Minister of Railways for the electrification of the Vienna tramway system, a recuperation exceeding 20% of the energy supplied to trains was guaranteed. It is obvious that in electrifying railways operating over heavy grades and also in urban service where stops are frequent, the feature of recuperation peculiar to certain types of alternating-current motors is a very substantial advantage. Without further discussion, the speaker thinks that Mr. White's statement of the relative advantages and disadvantages of direct-current and alternating-current, three-phase motors falls somewhat short of rendering full justice to the latter. Perhaps this was an unavoidable consequence of the condensation necessary in attempting to cover so important and varied a subject in a paper not excessive in length.

The data presented in the paper under discussion, which relate to the increased traffic resulting in certain instances from electrification, are striking and of great interest.

As regards cost of maintenance of electric rolling stock in heavy service, accurate and reliable data, based upon experience extending over a considerable number of years, cannot be had at present, but it is quite safe to say that the cost of maintenance of electric locomotives will not exceed one-third the cost of maintaining steam locomotives in a given service.

In comparing the two contrasted equipments, it is important to

note that the hours of actual service per day, or per annum, which steam locomotives are capable of rendering, are far less than electric locomotives could easily render. The speaker believes that the average freight locomotive on some important railways in the country travels only a distance approximating 75 miles a day. He can see no possible reason why electric locomotives traveling at the same average speed, say 15 miles per hr., cannot make at least double that mileage. It follows that, in electric traction, equivalent service can be performed with half, or less than half, as many locomotives as are required under conditions of steam operation. Mr. Stillwell

Referring to Mr. White's summary of conclusions, the speaker desires to emphasize the fact that he cannot agree with Mr. White in his statement that "in nearly all cases where electric conversion is justified direct-current motors alone deserve serious consideration"; on the contrary, he believes that the time has arrived when alternating-current motors, and not only the single-phase alternating-current motors which are now being placed upon the market, but also polyphase motors, should be given careful consideration. For short distances, undoubtedly conditions will usually be met to best advantage by the direct-current motor, but in certain cases of suburban service, many instances of interurban service and, particularly, in the substitution of electricity for steam upon existing railways, no engineer can afford to set aside alternating-current motors without careful investigation of their possibilities.

Mr. Siemens appears to assign to the alternating-current motor a much wider field of usefulness than Mr. White. The speaker considers Mr. Siemen's statement of the opinion generally accepted in Europe, *viz.*,

"That continuous-current motors are most suitable in cases where the speed of running has to be varied often and to a great extent, while alternating-current motors are most efficient in cases where long runs at constant speed are required,"

an accurate expression of the best engineering opinion in America as well as in Europe. In this opinion, many American engineers in considering the application of the two classes of motors in railway service have been misled by placing too much emphasis upon an experience which has to do chiefly with tramway service and, consequently, with motors which are called upon to start and stop at very frequent intervals. The problem was very materially changed when it became necessary to consider the application of motors in general railway service.

In this connection and reverting for a moment to consideration of relative advantages of tri-phase and single-phase motors, a point which has been published but not referred to in any of the papers read before the Congress, might be mentioned, *viz.*, the fact that single-phase motors require more weight on drivers for given draw-

Mr. Stillwell. bar pull than tri-phase or direct-current motors. The torque of the single-phase motor varies with the alternations; theoretically the average torque during a sinusoidal cycle is one-half the minimum. Tests made by Mr. Waterman, at Buda-Pesth, indicated that the ratio of weights required respectively by single-phase and tri-phase motors was approximately three to two instead of two to one. If there is any engineer who has accurate data in regard to the relation of weights required, respectively, by steam locomotives and locomotives having drivers actuated by absolutely uniform torque, it would be interesting to have it presented in this connection.

As regards efficiency of locomotives also, Mr. White has placed the relation of draw-bar pull to indicated horse power considerably higher than it has been placed by some other authorities.

Mr. White. J. G. WHITE, M. AM. SOC. C. E., New York City. (By letter.)—It seems to the writer that there are a few points in the discussion of his paper which justify further mention.

Students of history agree that to comprehend fully the true meaning of historical events, one must appreciate the social and political conditions of the periods in which events occur, and in addition the factors entering into the "atmosphere" of such periods. Similarly, any one sufficiently interested to read the paper above referred to will possibly better understand it after having some knowledge of the conditions under which it was prepared.

Frankly, the subject of the paper was crowded out of the mind of the writer for some months by pressure of one important business matter after another, and so the paper was finally written in London and was mailed within a week of the time at which the first sentence was dictated. The paper as originally written was practically twice as long as when printed, and more than half of the time spent upon it was devoted to reducing its length to a minimum. This process seems to have been slightly overdone in several places, where, except for this, the statements and arguments would have been clearer.

In commenting on the discussion, the writer will attempt to reply to each point made separately.

Mr. Stillwell says:

"Mr. White's statement of the question, upon the answer to which Mr. White says the advisability of substituting electric traction for steam will depend, would be improved by using the word 'maintenance' or the word 'up-keep' in place of 'depreciation.' It appears obvious that Mr. White did not intend to use the word depreciation. * * * The terms depreciation and amortization are properly synonymous, but neither should be confounded with maintenance."

In spite of the hurried preparation of the paper this sentence, which by inference covers the entire subject under discussion, was

worded exactly as it was intended it should be, and in reading it over the writer, with his understanding of the general problem, is at a loss to see how the sentence could be substantially improved. It is an interesting commentary on American franchise conditions that a man of the scholarly attainments of Mr. Stillwell should insist that "depreciation and amortization are properly synonymous." According to the Standard Dictionary, "amortization" is "the extinction or reduction of a debt through a sinking fund," while "depreciation" is "a lowering in value or worth." As used in the above sentence, the two words are not synonymous, nor does the sentence referred to confound either with "maintenance." Mr. White.

The sentence as originally written was:

"Will the net earnings under electric traction, after making proper allowance for depreciation, be sufficiently increased to meet fully all increased charges for interest and amortization and leave a larger surplus above fixed charges than is now being earned?"

According to the understanding of the writer, "net earnings," as used in the above sentence, is the amount which remains in each specific instance after having deducted all proper operating charges, and all incidental expenses, such as taxes, legal expenses, etc. In properly kept accounts, all items of "maintenance" or "up-keep" should be included in operating expenses, consequently, in using the expression, "net earnings," it was assumed that every one would understand that maintenance had already been provided for. "Depreciation," as defined by Mr. Stillwell, "designates an amount which should be set aside annually in every undertaking of the kind under discussion for the possible, perhaps probable, renewal of the entire plant at some future date." This defines substantially the writer's understanding of the word as used in his sentence above referred to.

To take cars as a specific example, it was assumed that ordinary repairs, perhaps the annual revarnishing, perhaps the bi-annual complete repainting, etc., would be taken care of in operating expenses, but that beyond this, from the "net earnings" there should be provided a fund which, in the course of a number of years, would be sufficient to replace original cars with new cars when the former were no longer fit for service. Fortunately, so far as American franchises are concerned, a fund for amortization is seldom required. This is particularly true as applied to steam railways. The latter usually have charters or franchises which cover a very long period, or are perpetual, and seldom, if ever, do the properties of such steam railways revert to municipalities, States, or to the General Government of the United States. In other countries, however, it frequently happens that after a period of years, sometimes comparatively short, the entire property of a steam railway or a tramway reverts to the General or Local Government without further compensation to the shareholders, or other security holders

Mr. White. of the company, than such as they have received out of earnings during the life of the concession. In all such cases, it is necessary to arrange for the "amortization" of the original cost of the entire property, or such portions thereof as revert to the Government without compensation under terms of concession.

Usually, in America, the financial arrangements for, and accounts of, both tramways and steam railways, make no provision for amortization, and such is not required. Frequently no real provision is made for depreciation. Even the latter has often been unnecessary because the increased earnings of properties from rapidly growing populations have permitted increased capitalization from time to time to provide sufficient funds to cover all depreciation, instead of the latter having to be provided from earnings. As the rate of growth of population of the country becomes slower, it will be increasingly necessary to provide for depreciation, and, where franchises are limited, to provide for amortization as well, and both these matters should be given such attention as they deserve in deciding whether or not expenditures for electrical equipment are advisable.

Mr. Stillwell is of the opinion that the writer's statement, "that ordinary trunk-line steam railways, under present conditions, are not suitable for electrical equipment," is very indefinite. As used, "ordinary" may be considered synonymous with "average" or "usual," and certainly almost all engineers will agree that these cannot now be advantageously equipped electrically. It seems to the writer that it is better to be indefinite than to try to fix a definite standard which, in many cases, will be unquestionably wrong.

Mr. Stillwell seems to be of the opinion that on all railways where the traffic per day per mile of double track exceeds 10 000 ton-miles, electrification is likely to be advisable, and above 15 000 ton-miles per day, is almost sure to be advisable. Such attempts at arbitrary rules are more likely than not to lead to wrong conclusions, because, of all present-day engineering problems, this general one of electrification most clearly demands that "all its factors should be carefully studied, because some of the items which may first seem insignificant are likely, on careful study, to develop greatly in importance."

On ordinary tramways, a traffic very far below 10 000 ton-miles per day per mile of double track would justify electrification. On ordinary suburban lines, electrification would probably be justified with a tonnage considerably less than that just mentioned. On the other hand, a road, of which practically the entire business consisted of trains hauling iron ore of a total tonnage of perhaps 3 000 tons per day, could not possibly justify electrification.

Mr. Stillwell points out that the paper

"Does not specifically call attention to the fact that an increase

in speed in itself has a two-fold value: (1) in making it possible to do a given business with rolling-stock equipment decreased in proportion to the increase in speed; and (2) by reason of the fact that the public is enormously attracted by the higher speed." Mr. White.

In the original draft of the paper these facts were both mentioned, but the first was considered axiomatic, and the second is mentioned in the paper.

Mr. Stillwell states that the approximate power requirements of the Manhattan Elevated Railway, as reported, are erroneous. The figures quoted by the writer were a power consumption of about 125 watt-hours (at the power station) per ton-mile, figuring train only, or 100 watt-hours per ton-mile, including live load. Mr. Stillwell states: "Including lights in cars and in sub-stations, the average figures for summer months are, at the power-house, 102 watt-hours per ton-mile, and, as delivered to trains, 82 watt-hours per ton-mile." If his figures include live load, they correspond exactly with the information which was furnished the writer. If not, the discrepancy is probably accounted for by the fact that the information which was furnished the writer covered an average of summer and winter conditions.

Mr. Stillwell is of the opinion that the paper understates the less cost per kilowatt than the figures given by the writer. This is true in certain localities. The statement, as made, was intended to be "safe" for general conditions, and is to-day only a reasonably safe figure for preliminary estimates. For other general purposes, detailed estimates should be prepared to cover the specific conditions applicable to each case under consideration. It was assumed that all engineers understand that the cost per kilowatt was based on its usual rated load and not on its peak-load capacity.

Mr. Stillwell is of the opinion that the paper understates the advantage of electric traction in decreasing the cost of maintenance-of-way. In this matter, as in others, particularly that of fuel consumption, the writer believes that his statements are conservative in the sense of under-estimating, if anything, the advantages of electric traction. It was deliberately intended that the advantages should be slightly under-estimated rather than over-estimated, the writer believing that conservatism in this respect was not only justifiable, but advisable, and likewise believing that in estimating costs it is better to be reasonably high rather than to under-estimate.

Mr. Stillwell thinks the writer under-estimates the saving in fuel by use in electric traction. This is probably true under favorable conditions. As above stated, however, the writer deliberately attempted to be conservative in this as in other matters. He endorsed the estimates of Messrs. Arnold and Potter, which were referred to in his paper. Messrs. Arnold and Potter stated that, in the experiments referred to, the coal consumption of the steam locomotive was

Mr. White. about 15.6 lb. of coal per effective h. p-hr. They further estimated that a large economically constructed electric power station could generate electric power with about 2½ lb. of coal per kw-hr., and that the average efficiency from switchboard to axles of motor car would be about 50 per cent.

Mr. Stillwell states that, in the Manhattan Station, power is being produced with 2.6 lb. of coal per kw-hr. at the switchboard, which corresponds very closely with the estimate above referred to. Mr. Stillwell further gives detailed percentages to show that on the Manhattan Elevated Railway the full-load efficiency from engine to wheels of motor cars is about 57%, and the average efficiency about 60 per cent. The Manhattan Elevated Railway presents an unusually favorable, instead of an average, set of conditions. Even here the writer does not believe that actual tests would show so high an efficiency as the theoretical figures given, and as the paper was intended to apply to average conditions rather than to especially favorable conditions, it seems to the writer that the general efficiency of 50%, as calculated by Messrs. Arnold and Potter, is sufficiently accurate for all ordinary estimates under average conditions.

Mr. Stillwell seems to think that automatic devices in connection with signal system should preferably apply air-brakes rather than cut-off current from motors. The former is probably simpler, and from this point of view, more desirable, but whether automatic devices installed should apply air-brake, and also cut-off current, or only one of the two, can be determined in connection with each installation. Furthermore, there are too many special conditions to be considered to permit of this matter being advantageously discussed in detail in a paper of this sort.

As to the advisability of running train lines carrying heavy currents, there is room for argument. It is evident that if wiring connections between cars are properly worked out, it is best to provide in some way so that if any collector shoe, or pair of collector shoes, should temporarily not act properly, nearby motors will be supplied from other collectors. It seems equally evident that wires on cars carrying heavy currents should be as short as possible consistent with other requirements; that all joints should be made so as to prevent any chance of arcing, which might in any way set fire to cars; and that every precaution should be taken to see that, from the collector shoe to and through the controlling devices, and on, to and through the motors, and to the wheels, no place should be left where it would be possible for an arc to form which might set fire to cars, or for any wires to become so overheated as to impair the insulation.

Mr. Stillwell objects to the way in which the writer stated the probable relative losses as between direct and alternating-current systems. The paper throughout was intended to apply to usual

commercial practice and conditions and not to possible, but impractical, conditions. It was on this general assumption that the statement was made that, in cases where direct current is directly applicable, losses are easily restricted to 15%, but that with greater distances, where the use of combined alternating and direct-current systems would be advisable, the average losses would be likely to approximate 24 per cent. As above stated, this applies to usual commercial conditions, and, with combined alternating and direct-current systems, assumes reasonable average losses in primary circuits, step-down transformers, rotary transformers, and secondary distributing circuits, including return, whether the latter consists of running rails or not. Mr. White.

Mr. Stillwell objects to the statement that direct-current motors possess the advantages of being of cheaper and simpler construction and lighter weight. He says that there are no inherent properties which compel this condition. This is true, as applied to stationary motors, and would be true as applied to traction motors if reasonable wear of bearings did not have to be allowed for. To provide reasonably for wear of motor bearings, a considerable air gap is surely required, and if the latter is provided, alternating motors, including controlling devices and other accessories, will, under average conditions, weigh more than direct-current motors of equal capacity. This is not only true of motors of American manufacture, but will be clearly proven if one compares the weights and capacities of motors on the two Italian lines discussed in the paper, one of which is equipped with direct-current, and the other with alternating-current motors.

Mr. Stillwell objects to the writer's use of the words "carrying capacity" in enumerating the disadvantages of the alternating as compared to the direct-current system. The words "carrying capacity" in this sentence were not used in the narrow, strictly technical and specific sense in which "carrying capacity" is used as applied to fuses, in which case the "carrying capacity" is determined by the melting point of such fuses. In the sentence, the words were used in the broad sense, and it was assumed that every engineer in reading the sentence would understand that the "carrying capacity" of running rails is determined, not by the melting point of such rails, but by the allowable drop in potential.

To meet the case of an engineer who would not understand what would be the determining factors in the carrying capacity of running rails, the sentence might be more clearly stated as follows, which is the original sentence with the part in brackets added:

"Experiments recently reported by the General Electric Company state that the carrying capacity of the two trolley wires and double track (as determined by allowable drop in potential) was 1.76 times as great with direct as with alternating 25-cycle current,

Mr. White. and that the track alone had a carrying capacity (as determined by allowable drop in potential) with direct current 6.55 times as great as with alternating current."

It never occurred to the writer that any one could misunderstand the term "carrying capacity" as applied to running rails, and as used in the above sentence.

Mr. Stillwell objects to the writer's general conclusion that, in nearly all cases where electric conversion is justified, direct-current motors alone deserve consideration, although the writer admits in the paper that under certain general circumstances the advantages of single-phase motors should be carefully considered with those of direct-current motors, and that in occasional, but unusual, conditions three-phase motors might deserve careful study and comparison. Since the paper was prepared, there have been additional improvements in single-phase motors as applied to traction, and the writer hopes that the confidence of many engineers in the single-phase equipments will be proven by their success in actual commercial use during the next two or three years.

Mr. Stillwell states, "Mr. Siemens appears to assign to the alternating-current motor a much larger field of usefulness than Mr. White." Mr. Stillwell considers Mr. Siemens' statement with regard to this as an accurate expression of the best engineering opinion in America and Europe. Mr. Siemens' statement was as follows:

"That continuous-current motors are most suitable in cases where the speed of running has to be varied often and to a great extent, while alternating-current motors are most efficient in cases where long runs at constant speed are required."

The writer agrees that this is a fair summation of the case. He further adds that cases where long runs at constant speed are required, are likely to be those where the cost of electric conversion is not justified, and up to date very few cases "where long runs at constant speed are required" have been found which, at the same time, would permit of the investment required for electrical conversion.

At the time the paper was written there was, so far as the writer knows, not a single railway or tramway in America being regularly and commercially operated by alternating-current motors. In some hundreds of cases of electric traction which were carefully considered by various engineers known to the writer during the period from 1887 to the date at which the paper was prepared, and including tramways, interurban railways, underground and elevated railways, steam railways, and industrial railways, there were a few cases where alternating-current motors deserved consideration, but not one case where their use, after careful study of the relative advantages and disadvantages, proved to be advisable. The fact that there was not an alternating-current road in commercial operation in America at that date is conclusive proof that other engineers, not known to the writer, reached similar conclusions.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

STEAM TURBINES.

Congress Paper No. 62.

SOME TYPICAL TESTS OF STEAM TURBINES.

By Francis Hodgkinson, M. Am. Soc. M. E.,
East Pittsburg, Pa., U. S. A.

Discussion on the Subject by

M. L. Holman, St. Louis, Mo., U. S. A.
G. O. M. Olsson, Stockholm, Sweden.
J. N. Chester, Pittsburg, Pa., U. S. A.
Charles Hermany, Louisville, Ky., U. S. A.
Elmo G. Harris, Rolla, Mo., U. S. A.
Charles A. Hague, New York City, U. S. A.
F. R. Low, New York City, U. S. A.
Karl P. Dahlstrom, Stockholm, Sweden.
R. N. Ehrhart, East Pittsburg, Pa., U. S. A.
Francis Hodgkinson, East Pittsburg, Pa., U. S. A.

Note —Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 62.

STEAM TURBINES.

SOME TYPICAL TESTS OF STEAM TURBINES.

By Francis Hodgkinson, M. Am. Soc. M. E.

In June, 1904, the writer had the honor of presenting a paper before the American Society of Mechanical Engineers, on the subject of Steam Turbines, in which he endeavored to discuss some of the theoretical and practical considerations involved. Therein were briefly described the different types of turbines which have been built commercially, also, more particularly, the Westinghouse-Parsons turbine, a great many of which have been built in the United States.

It is proposed in this paper, to give details of some tests lately made on turbines, and to describe the methods of making such tests.

As steam turbines have been built commercially in the United States only during a few years, purchasers have given much attention to builders' guaranties of steam consumption, and, furthermore, have been generally insistent upon thorough tests being made to demonstrate that the guaranties were made good.

Doubtless, as time goes on and the steam turbine becomes better known, such thorough tests will not be insisted upon for every unit sold. Each machine will not be required to undergo elaborate

economy tests, any more than is customary to-day in the case of reciprocating engines.

Up to the present time, almost every steam turbine built has had thorough economy tests made upon it in the presence of the purchaser or his representative.

The Westinghouse Machine Company has a thoroughly equipped testing room with ample condenser and boiler capacity available, and has records of accurate tests of a large number of steam turbines, which it has built, operating under quite a variety of vacua, superheats, boiler pressures, etc.

The paper previously referred to contains a table giving the results of a number of these tests, it being believed that a much better opinion of the merits of a machine could be formed by examining a large number of careful tests corroborating each other, rather than by the examination of a single test. In this table will be found 124 economy tests on 19 individual machines.

The plan of the testing room is shown in Plate I, there being one set of foundations for five turbines up to 500 kw. capacity, in conjunction with a complete surface-condenser equipment, the condenser itself having 3 000 sq. ft. of surface.

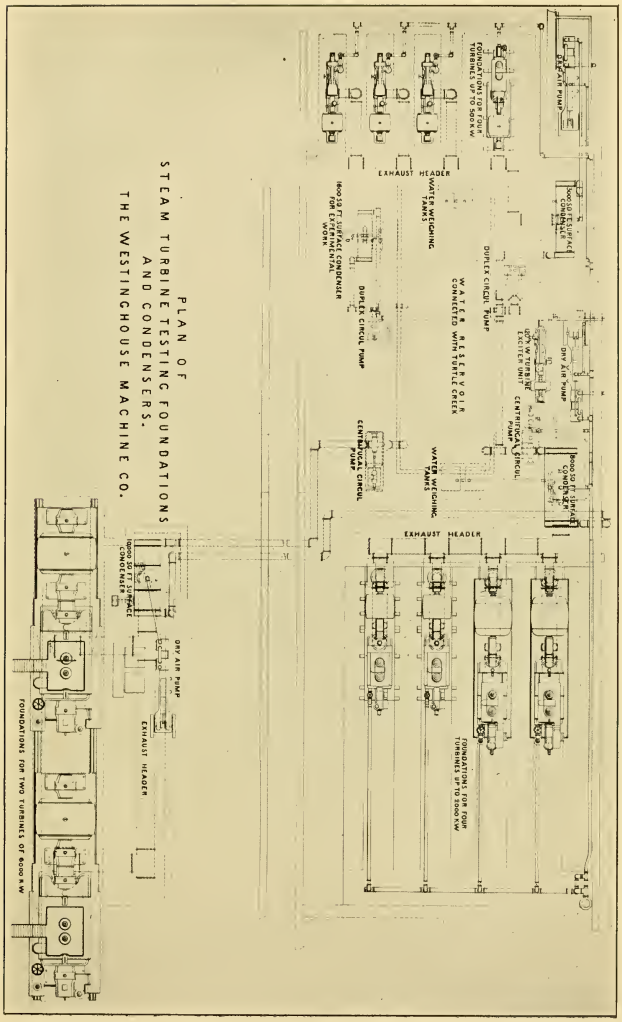
There is a further set of foundations suitable for four turbines with capacities ranging from 750 to 2 000 kw., in conjunction with a complete surface-condenser equipment of 8 000 sq. ft. of surface.

In the main erecting-shop building, also shown in Plate I, are foundations with accommodation for two turbines of 6 000 kw. capacity, with a 10 000-sq. ft. surface condenser provided with its complete complement of pumps, etc. Such a condenser, of course, is inadequate for testing such large units at full load, but, in this case, the builder must be satisfied with testing at fractional loads only. To carry loads beyond this would exceed the capacity of the available boilers. It has been possible, however, to carry more than half load on one of the 5 500-kw. turbines which have been tested.

Fig. 1, Plate II, illustrates these foundations, with two of the 5 500-kw. turbines actually undergoing test, the third turbine is in process of erection, and, in due course, will be moved to one of the foundations for test.

A better idea of the turbine itself is given in Fig. 2, Plate II, which also shows the water brake by which the turbine is loaded.

PLATE I. VOL. LIV. PART E.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
HODGKINSON ON
STEAM TURBINES.



PLAN OF
STEAM TURBINE TESTING FOUNDATIONS
AND CONDENSERS.
THE WESTINGHOUSE MACHINE CO.

As will be seen further, tests are nearly always made with a water brake, rather than with the electric generator which will subsequently become a unit with the turbine. By this means, the difficulty of keeping the load constant by water-rheostats is eliminated, together with all the uncertainties of electrical instruments. The exact load desired can be put on the machine and adjusted in a very few minutes, while electro-rheostats take much practice and always considerable time in order to be put into condition to hold a given load constant for any length of time.

If high-tension currents are used, an element of danger is involved, and, also, continual trouble due to the burning out of portions of the wet tanks.

The water brakes used consist simply of a rotating element revolving in a stationary casing, the weight of the latter being carried on the shaft by bearings which are provided. The work of the turbine is taken up in the fluid friction of the revolving part in the water which is furnished within the stationary casing.

The load is adjusted by varying the quantity of water, and is measured by reading the torque of the stationary element upon an ordinary platform scale, in precisely the same manner as in the case of the ordinary Prony brake.

A large proportion of the water escapes in the form of steam, so that much less cooling water is necessary than with the ordinary Prony brake.

The boilers are about 500 ft. from the nearest turbine foundation, and at a point in close proximity with the turbines is a superheater, by which a fair degree of superheat can be obtained. The capacity of the superheater, as at present installed, is such that 150° of superheat can be carried on a turbine developing about 2 000 h. p.

As convenience, rather than economy of operation, is desired, the superheater is fired with natural gas. The quantity of brick settings, arches, etc., in the installation was kept as small as possible, in order to give small heat inertia to the superheater, so that the amount of superheat would respond quickly to adjustment of the gas-burners, and permit the superheat to be adjusted quickly and kept constant during a test.

Because of the great distance between the boilers and the turbines, it is difficult to get dry steam adjacent to the turbines, so that, when it is desired to operate with dry saturated steam, the

superheater is used and adjusted to give dry saturated steam to the turbine under test. In all cases, the temperature of the steam at the throttle is read, and careful calorimeter readings are also taken.

The calorimeters used are of the ordinary throttling type, and have been made the subject of careful consideration. As they are used, not so much for measuring moisture, as for discovering whether the steam is dry saturated, the question of where the sample is taken becomes less important.

It has been found, however, that calorimeters, as frequently constructed, will read the steam to be wet when it actually carries some superheat.

Frequently, calorimeters are made with an orifice too small for the steam to expand in, consequently, radiation losses cannot be considered negligible.

It has been found desirable to have the diameter of this orifice not less than $\frac{5}{32}$ in., or $\frac{3}{16}$ in. Furthermore, it has been found that if the jet issuing from the orifice impinges on the thermometer well, it will have the effect of cooling the thermometer, thus giving an incorrect temperature reading.

Good results have been attained by placing three or four screens in front of the jet, so that the steam, as far as possible, may be brought to rest before it comes in contact with the thermometer well.

The accuracy of the calorimeter is tested by taking samples from the steam pipe, the steam passing through which carries 1 or 2° of superheat, the temperature of this steam being measured by a thermometer known to be correct.

Thermometers are calibrated by passing steam, known to be wet, through the steam pipe where the test is to be made, the pressures at the same time, of course, being carefully read. If the thermometer is correct, its reading will correspond with the temperature of the saturated steam.

Pressure gauges, in their turn, are calibrated with a Crosby gauge-tester, and care is always exercised during tests to see that a siphon prevents the gauge from becoming heated.

It has been found desirable that thermometers be calibrated in the same wells in which they will be placed during the test, as different degrees of immersion seem to affect the thermometer readings.

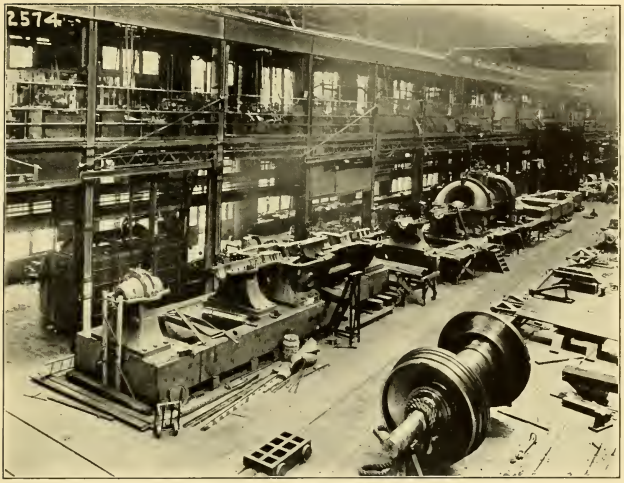


FIG. 1.—FOUNDATIONS FOR 5 500-KW. STEAM TURBINE.

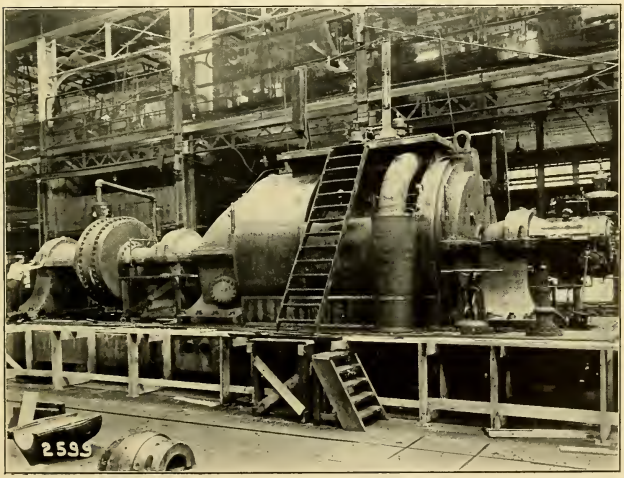


FIG. 2.—STEAM TURBINE, WITH WATER BRAKE.

From the foregoing, it will be seen that no pains are spared, and that the condition of the steam entering the turbine is known with sufficient accuracy.

The steam leaving the turbine passes through its exhaust pipe into a header. All the exhaust pipes at this point are furnished with the large exhaust valve shown in Fig. 1. The valve itself consists of a plain conical disc having a rubber seat. The pressure keeps the valve to its seat and turbines, other than the one under test, may be opened up for examination without fear of causing an air leak into the condenser, or may even be operated

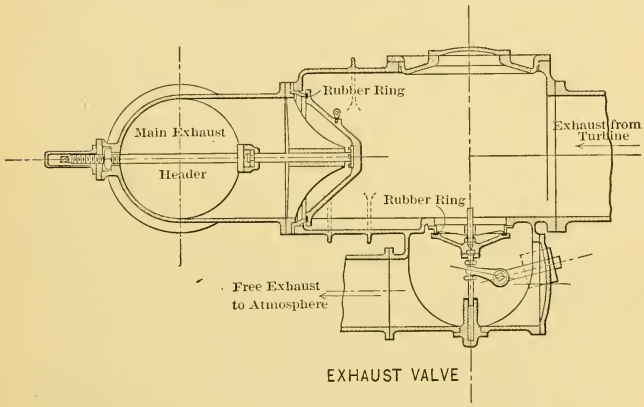


Fig. 1.

by exhausting to the atmosphere through another valve of similar construction shown in the illustration.

The rubber seats last for years, and the valves give no trouble from leakage.

The exhaust steam enters at the bottom of the surface condenser where a hot well is provided into which all the condensed steam drains, and from which it is pumped to the weighing tanks, where it is accurately weighed. A dry air-pump takes the non-condensing vapors from the top of the condenser.

The air-pumps are all of the well-known dry vacuum type, having

two cylinders through which the vapors pass in series. The pumps are driven by a single cylinder equipped with Corliss valve gear.

It is found that the air-pump will extract a small amount of moisture with the non-condensable vapors. This has been measured on two or three occasions, and found to average about 40 lb. per hr.

As it is necessary to test various turbines with a vacuum corresponding to the vacuum which will exist in the purchaser's power plant, and under which conditions the guaranties of performance have been made, it is frequently necessary to carry vacua considerably lower than the normal high vacuum which the condenser is capable of furnishing. The lowering of the vacuum is sometimes accomplished by varying the speed of the circulating pump. Usually, however, a small quantity of air is permitted to leak into the condenser through a small valve, and the vacuum adjusted in this manner.

TABLE 1.—Brake Readings.

East Pittsburg, Pa., July 6th, 1904.

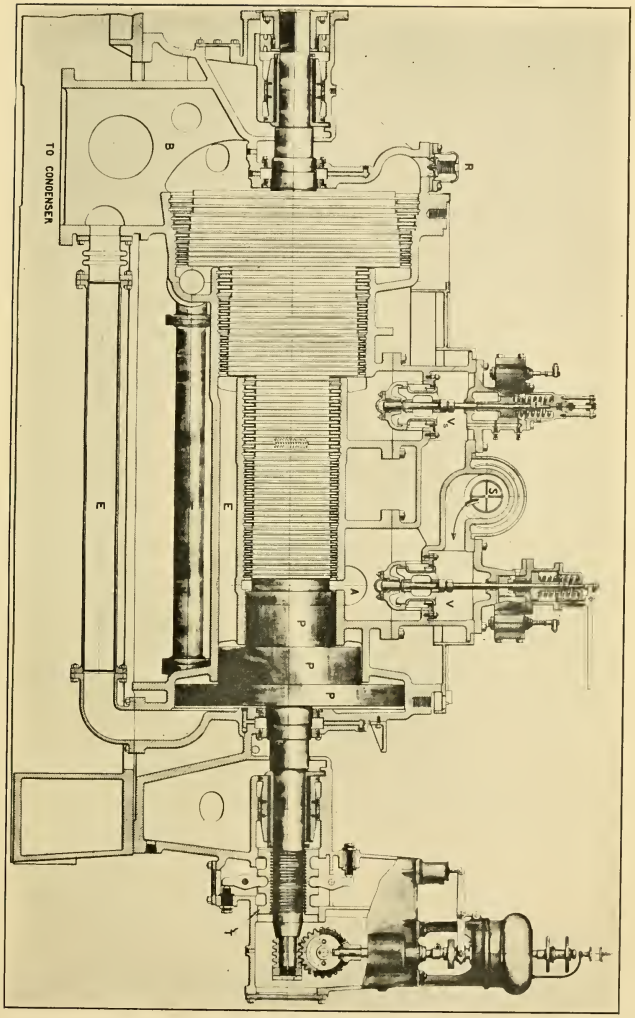
Turbine No. 60. Test No. 10. 750 kw. 1 800 rev. per min. Brake No. ———. Brake radius, $44\frac{3}{16}$ in. Dead weight, 104 lb. Nominal load during test, 1 000 h. p.

Time. P. M.	Gross scale weight.	Time. P. M.	Gross scale weight.	Time. P. M.	Gross scale weight.	Time. P. M.	Gross scale weight.	Time. P. M.	Gross scale weight.
9.10	905	9.23	906	9.36	906	9 49	907	10.02	911
.11	904	.24	906	.37	905	.50	905	.03	915
.12	906	.25	906	.38	905	.51	905	.04	915
.13	906	.26	906	.39	907	.52	905	.05	915
.14	906	.27	906	.40	909	.53	905	.06	915
.15	905	.28	906	.41	908	.54	905	.07	915
.16	905	.29	906	.42	910	.55	904	.08	915
.17	906	.30	906	.43	910	.56	902	.09	915
.18	906	.31	906	.44	910	.57	906	.10	915
.19	907	.32	906	.45	910	.58	903	.....	.....
.20	907	.33	906	.46	907	.59	912	.....	.....
.21	906	.34	905	.47	905	10.00	911	.....	.....
.22	907	.35	906	.48	903	.01	911	.....	.....

H.p. = 1025.3.

Average gross weight.....907.6 lb.
Dead weight.....104 lb.
Net weight.....803.6 lb.

Signature of observer, H. O'Donnell.



LONGITUDINAL SECTION OF WESTINGHOUSE-PARSONS STEAM TURBINE.

The glands used on these turbines require water for sealing, and small quantities of this water find their way, by leakage and evaporation, into the exhaust of the turbine. For this leakage correction must be made, and for its measurement a small pump and a weighing tank are provided, all of which are made part of a circulatory system. The quantity of water leaking into the exhaust is thus accurately measured and recorded, as in Table 3.

TABLE 2.—Weights of Condensed Steam.

East Pittsburg, Pa., July 6th, 1904.

Turbine No. 60. Test No. 10. 750 kw. 1 800 rev. per min. Nominal load during test, 750 kw. 1 000 h. p.

Time. P. M.	Dead weight.	Gross weight.	Net weight.
9.15	1 390	2 546	1 156
.20	1 367	2 542	1 175
.25	1 390	2 560	1 176
.30	1 367	2 525	1 162
.35	1 390	2 552	1 162
.40	1 367	2 522	1 155
.45	1 290	2 537	1 147
.50	1 368	2 528	1 160
.55	1 390	2 544	1 154
10.00	1 367	2 526	1 159
.05	1 390	2 550	1 160
.10	1 367	2 540	1 173

Water level in hot well, 0 in. above / below point at commencement of test.
Diameter of hot well, 36 in.
Net pounds of steam condensed per hour, 13 516.

Total condenser discharge per hour	13 933 lb.
± Hot-well correction	0 lb.
—Gland leakage	280 lb.
Condenser leakage	137 lb.
	13 516 lb.

Signature of observer, W. G. Swift.

In further explanation of the foregoing description of the methods of test, are given Tables 1 to 5 which form a complete log of a single test. The result of this particular test is also incorporated in Table 7.

Tables 1 to 5 are filled out on separate blank forms by the different observers, all being subsequently worked up and bound into a folder.

The surface condensers, of course, are tested for leakage, both before and after each series of tests.

TABLE 3.—Gland Leakage.

East Pittsburg, Pa., July 6th, 1904.

Turbine No. 60. Test No. 10. 750 kw. Volts, ———. Phase, 1 800 rev. per min.

Time. A. M. P. M.	Weight of tank. in pounds.	Leakage of glands.	Time. A. M. P. M.	Weight of tank, in pounds	Leakage of glands.
9.10.....	525	.....	9.45.....	360	.....
.15.....	504	21	.50.....	336	24
.15.....	504	.....	.50.....	336	.....
.20.....	485	19	.55.....	310	26
.20.....	485	.....	.55.....	310	.....
.25.....	455	30	10.00.....	290	20
.25.....	455	.....	10.00.....	290	.....
.30.....	426	29	.05.....	268	22
.30.....	426	.....	.05.....	268	.....
.35.....	403	23	.10.....	245	23
.35.....	403	.....	.....	.....	.....
.40.....	381	22	.....	.....	.....
.40.....	381	.....	.....	.....	.....
.45.....	360	21	.....	.....	.....

Total leakage..... 280
Gland leakage per hour..... 280

Signature of observer, Hugh A. Trax.

The Westinghouse-Parsons steam turbine is so well known that a thorough description of it would be out of place in this paper. A longitudinal section through a turbine of this type is shown in Plate III, and this is precisely similar to those turbines the tests of which are described later.

Since writing the paper for the American Society of Mechanical Engineers, before referred to, the building of several turbines has been completed, and the tests which have been made on them are of much interest; tests on Turbines Nos. 59, 60, 68, 95 and 96 having been witnessed by representatives of the purchasers.

Fig. 2 shows the results of tests on a turbine of 750 kw. capacity and of the type shown in Plate III. This turbine was designed for operation with high vacuum, nevertheless, tests were made without vacuum. The best result was attained under normal operating conditions at about 20% overload. By means of the secondary valve, it was possible to carry double load, the steam consumption increasing slightly as the load became higher. At double load, the steam consumption was about 11% greater than at the most economical load. This percentage would probably have been less had

TESTS OF 750 K. W. TURBINE No. 59
BUILT BY
THE WESTINGHOUSE MACHINE COMPANY
EAST PITTSBURG, PA.
150 LB. BOILER PRESSURE
1200 REVOLUTIONS PER MINUTE
Total Pounds of Water per Hour
40 000
38 000
36 000
34 000
32 000
30 000
28 000
26 000
24 000
22 000
20 000
18 000
16 000
14 000
12 000
10 000
8 000
6 000
4 000
2 000
0
A
B
C
D
A'
B'
C'
D'
¼ Load
½ Load
¾ Load
Full Load
1¼ Load
2.0 Load
500
1 000
1 500
2 000
2 500
Brake Horse-Power
A Non-condensing, Dry and Saturated Steam – Total Water per Hour
A' Same conditions – Water per Brake Horse-Power per Hour
B Non-condensing, Steam Superheated 100 Fahr. – Total Water per Hour
B' Same conditions – Water per Brake Horse-Power per Hour
C 28-in. Vacuum, Dry and Saturated Steam – Total Water per Hour
C' Same conditions – Water per Brake Horse-Power per Hour
D 28-in. Vacuum, Steam Superheated 100 Fahr. – Total Water per Hour
D' Same conditions – Water per Brake Horse-Power per Hour
Curve No. 6078
30
28
26
24
22
20
18
16
14
12
Pounds of Water per Brake Horse-Power-Hour

FIG. 2.

the vacuum not fallen somewhat, due to the restricted area of the exhaust pipe when carrying such abnormal loads.

TABLE 4.—Pressure and Temperature Readings.

East Pittsburg, Pa., July 6th, 1904.

Turbine No. 60. Test No. 10. 750 kw. 1 800 rev. per min. 1 000 h. p.

Time. P. M.	Boiler pressure. A	Throttle pressure. B	Horse-power inlet pressure.	Vacuum as indicated by mercury column.	Temperature at throttle. B	Tachometer.	Continuous counter.	Counted strokes per minute.	Barometer.
Inst. No.	14 179	4 201	9 101	.....	26	.....	23/2	.....	.....
9.10	156	150	1·7	25.3	514	1 100	88 608	.....	29.33
.15.....	156	150	108	25.4	507	1 102	89 398	.....	.....
.20.....	158	154	108	25.3	507	1 104	90 188	.....	.....
.25.....	157	152	108	25.3	508	1 102	90 979	.....	.....
.30.....	154	149	108	25.3	510	1 100	91 771	.....	.....
.35.....	158	153	107	25.3	515	1 102	92 563	.....	.....
.40.....	157	153	108	25.3	520	1 104	93 355	.....	.....
.45.....	156	150	108	25.3	517	1 103	94 146	.....	.....
.50.....	155	150	108	25.3	510	1 103	94 938	.....	.....
.55	158	154	106	25.3	510	1 104	95 730	.....	.....
10.00.....	157	153	108	25.3	512	1 104	96 524	....	.....
.05.....	156	150	108	25.3	514	1 102	97 316	.....	.....
.10	157	152	108	25.3	517	1 102	98 101	.....	.....
Average.....	157.5	151.5	107.7	25.31	512.4	1 102.5	.....	158.3	29.33
Calibrations...	— 0.5	— 0.8	— 2.2	.....	— 0.1	.....	.....	23/2	.....
Corrected readings.....	157	150.7	105.5	25.31	512.3	.....	.....	1820.5	29.33

Signature of observer, W. G. Cogley.

The economy of the same machine, tested without superheat, is plotted on the same curve sheet.

Such tests, however, were not carried above normal full load. The only reason this was not done was because of the limited time available for making tests on any one machine.

When operating without vacuum and with 100° superheat, it will be observed the best result was about 23 lb. per b. h. p-hr.

Tests were run under these conditions at very nearly 50% overload, when the steam consumption was about 23.4 lb. per b. h. p-hr.

Total pounds of steam per hour.
20 000
19 000
18 000
17 000
16 000
15 000
14 000
13 000
12 000
11 000
10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
ECONOMY TESTS OF
750 K.W. STEAM TURBINE NO. 60,
BUILT BY
THE WESTINGHOUSE MACHINE CO.
EAST PITTSBURG, PA.
150 LB. STEAM GAUGE PRESSURE.
1 800 REVOLUTIONS PER MINUTE.
150° FAHR. SUPERHEAT.
B
A
A – Total steam consumption per hour, 28 in. vacuum.
B – " " " " " 26 in. "
A1 – Pounds steam per brake horse-power-hour, 28 in. vacuum.
B1 – " " " " " " 26 in. "
B1
A1
Curve No. 60 740
400
500
600
700
800
900
1 000
1 100
1 200
1 300
1 400
1 500
Brake horse-power
10
12
14
16
18
20
22
24
26
28
Pounds of steam per brake horse-power-hour.

FIG. 8.

TABLE 5.

East Pittsburg, Pa., July 6th, 1904.

Test No. 10. Turbine No. 60. 750 kw. 1 800 rev. per min.

Time from 9.10 to 10.10 P. M.	
Throttle pressure on gauge in pounds, per square inch	150.7
High pressure, inlet pressure in pounds per square inch, on gauge	105.5
Vacuum in low-pressure outlet as indicated by mercury column.	25.81
Vacuum referred to 30-in. barometer	25.98
Barometer	29.53
Temperature at throttle in degrees fahrenheit	512.3
Superheat at throttle in degrees fahrenheit	146.6
Speed shown by continuous counter	1820.5
Load in brake horse-power	1025.0
Total net pounds of steam condensed	13516.
Pounds of steam per brake horse-power hour	13.18

Calculations made by J. V. Davidson.

One test was run with neither vacuum nor superheat, showing a full load economy of 28.2 lb. per b. h. p-hr. The average readings of all these tests are shown in Table 6.

It is possible that records of tests on steam engines may be found which will show, in some respects, a higher economy than here shown, but in this series of tests is demonstrated the enormous flexibility of the steam turbine for operating under all kinds of conditions, and under no one of these can the performance be said to be bad. There is a great flexibility of overload, surely enough to satisfy the most exacting demands of street-railroad work.

It must be understood, of course, that no adjustments are necessary to permit the turbine to operate under all these different conditions. The secondary governor valve is entirely automatic, requiring no hand manipulation whatever.

In Fig. 3 are shown the results of tests on a similar machine operating with 150° superheat and both 26 and 28-in. vacua. The machine is precisely the same as the one already described, although tests were not made under so many varying conditions, and are, in this respect, not so spectacular. The details of these tests are given in Table 7.

Another turbine of the same type gave the results shown in Fig. 4, and also the detailed results shown in Table 8, when operating with a 28-in. vacuum and 100° superheat. The close agreement between these tests and some of those shown in Fig. 2 when

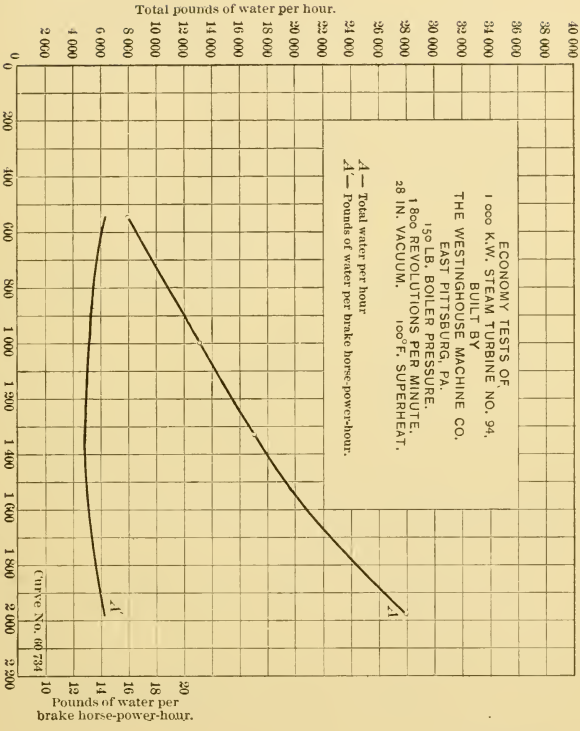

ECONOMY TESTS OF
1 000 K.W. STEAM TURBINE NO. 94,
BUILT BY
THE WESTINGHOUSE MACHINE CO.
EAST PITTSBURG, PA.
150 LB. BOILER PRESSURE
1 800 REVOLUTIONS PER MINUTE.
28 IN. VACUUM. 100°F. SUPERHEAT.
A — Total water per hour
A' — Pounds of water per brake horse-power-hour.
Total pounds of water per hour.
40 000
38 000
36 000
34 000
32 000
30 000
28 000
26 000
24 000
22 000
20 000
18 000
16 000
14 000
12 000
10 000
8 000
6 000
4 000
2 000
0
0
200
400
600
800
1 000
1 200
1 400
1 600
1 800
2 000
2 200
Brake-horse-power.
Curve No. 60 734
10
12
14
16
18
20
Pounds of water per brake horse-power-hour.

Fig. 4.

operating conditions were similar, bears testimony to the general accuracy of the testing methods used.

TABLE 6.—Tests of 750-kw. Turbine No. 59.

Operating with 150 lb. Boiler Pressure, 28-in. Vacuum and 100° Superheat, at 1 800 rev. per min.

Test Number.	Percentage of nominal full load.	Throttle pressure on gauge, in pounds per square inch.	Vacuum referred to 30-in. barometer.	Superheat at throttle, in degrees fahrenheit.	Quality shown by calorimeter.	Speed shown by continuous counter.	Load, in brake horse-power.	Total net pounds of steam confessed.	Pounds of steam per brake horse-power hour.
20.....	0.327	154.7	28	100.11	.....	1 791.7	354.96	5 439	15.32
19.....	0.656	150.8	28.07	102.64	.....	1 797.5	712.03	9 450	13.27
12.....	1.03	151.4	28.01	99.07	.....	1 804.35	1 115.1	13 808.4	12.38
11.....	1.43	150.9	27.85	99.72	.....	1 787.8	1 554.3	20 202.4	12.99
21.....	1.98	150.1	26.42	92.91	.....	1 769.8	2 146.78	29 874	13.91

Operating Non-Condensing with 140 lb. Boiler Pressure and no Superheat, at 1 800 rev. per min.

16.....	0.991	140.1	.....	.....	99.92	1 771	1 074.7	30 371	28.26

Operating with 150 lb. Boiler Pressure, 28-in. Vacuum and Dry Saturated Steam, at 1 800 rev. per min.

15.....	0.198	151.9	28.04	.....	100.07	1 817	215.64	4 291	19.89
14.....	0.521	151	28.01	.....	99.84	1 812	565	8 771	15.52
13.....	0.748	149.8	28.01	.....	99.83	1 811	811.04	11 759	14.49
10.....	1.028	149.5	27.97	.....	99.85	1 809	1 126.1	15 506.8	13.77

Operating Non-Condensing with 150 lb. Boiler Pressure and 100° Superheat, at 1 800 rev. per min.

23.....	0.366	155.5	.....	96.68	.....	1 797.4	397.7	12 665	30.33
22.....	0.702	153.5	.....	93.94	.....	1 776.5	761.06	18 308	24.06
24.....	1.42	149.4	.....	85.33	.....	1 759.5	1 544.56	36 248	23.46

Another machine of the same type, operating without superheat and with 26 and 28-in. vacua, gave the results shown in Fig. 5 and Table 9.

Of the smaller sized turbines, Fig. 6 shows tests on a 400-kw. machine operating with a 28-in. vacuum, both with 100° superheat and with dry saturated steam, and loads up to 100% overload. The close agreement will be noted between these tests and those under similar operating conditions on another machine of the same size tested by Mr. F. W. Dean, of the firm of Dean and Main.

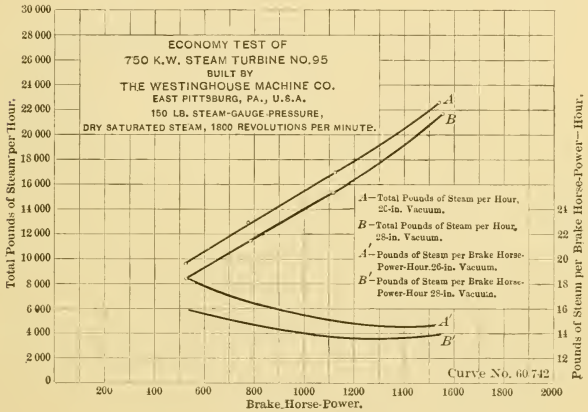


FIG. 5.

of Boston, the results of which have been published quite extensively.

The question is frequently asked, how suitable is a turbine for operating with vacuum during the summer, but made to exhaust against back pressure during the winter, when the exhaust steam is used for heating?

In Fig. 7 and Tables 11 and 12 is shown the performance of a turbine which during the winter is expected to operate against a back pressure of 8½ lb. per sq. in. above atmosphere, as already de-

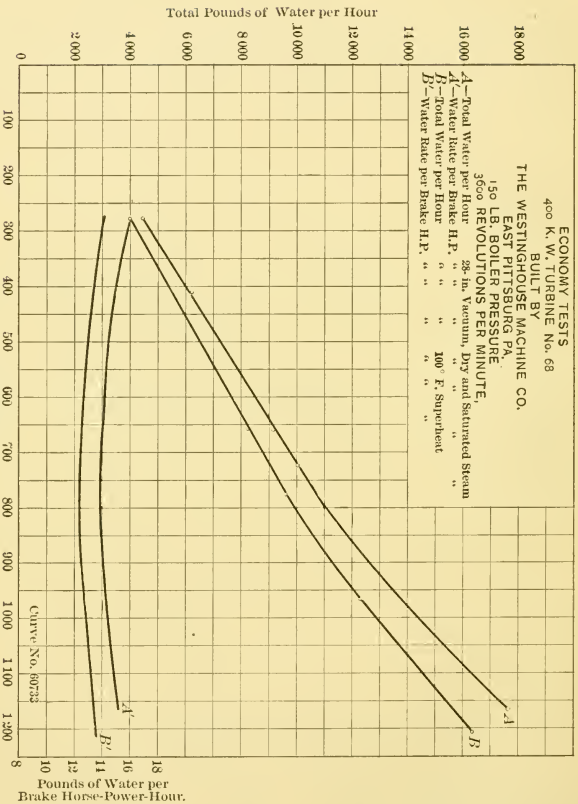

ECONOMY TESTS
400 K. W. TURBINE No. 68
BUILT BY
THE WESTINGHOUSE MACHINE CO.
EAST PITTSBURG PA.
150 LB. BOILER PRESSURE
3600 REVOLUTIONS PER MINUTE.
A—Total Water per Hour
A'—Water Rate per Brake H.P.
B—Total Water per Hour
B'—Water Rate per Brake H.P.
28 in. Vacuum, Dry and Saturated Steam
" " " "
" " " "
100° F. Superheat
" " " "
Total Pounds of Water per Hour
0
2 000
4 000
6 000
8 000
10 000
12 000
14 000
16 000
18 000
100
200
300
400
500
600
700
800
900
1 000
1 100
1 200
Brake Horse-Power
Curve No. 60733
8
10
12
14
16
18
Pounds of Water per Brake Horse-Power-Hour.

Fig. 6.

scribed. During the test, this turbine carried 1 178 b. h. p., with a back pressure of 9.2 lb. per sq. in. above atmosphere. The arrangement of the condensers, etc., in the testing room, precluded the measurement of the steam consumption while the turbine was operating with such back pressure, but the results of tests under normal operating conditions are given in order to show that for the sake of capacity with such a high back pressure, the economy of the turbine, when operating under normal conditions, was not sacrificed. It will be seen that the turbine is not materially under-loaded when operating at normal full load with vacuum.

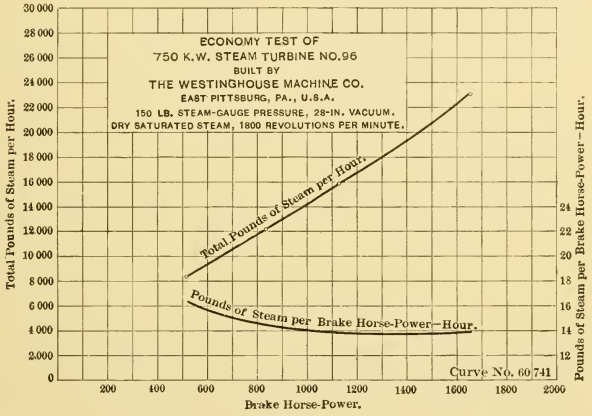


FIG. 7.

These few records of performances of turbines are evidence of their all-round economy.

The fact that turbines of 36 000 kw. total capacity, the product of one builder, are at the time of writing in successful operation, or in course of erection in the field, is proof of their operativeness. That power users have confidence in their future, is shown by the fact that this one builder alone has turbines of 92 000 kw. total capacity in course of construction, in addition to those already shipped.

TABLE 7.—Test of 750-kw. Turbine No. 60.

Operating with 150 lb. Boiler Pressure, 26-in. Vacuum and 150° Superheat, at 1 800 rev. per min.

Test number.	Percentage of nominal full load.	Throttle pressure, on gauge in pounds per square inch.	Vacuum referred to 30-in. barometer.	Superheat at throttle, in degrees Fahrenheit.	Quality shown by calorimeter.	Speed shown by continuous counter.	Load, in brake horse-power.	Total net pounds of steam condensed.	Pounds of steam per brake horse power-hour.
9.....	0.482	152.5	25.98	149.2	.....	1 818.2	523.5	8 459	16.04
10.....	0.924	150.7	25.98	146.6	.....	1 820.5	1 025.3	13 516	13.18
14.....	1.18	148.7	26.02	147.9	.....	1 803.2	1 285.2	16 776	13.05
15.....	1.41	145	25.97	144.2	.....	1 803.2	1 536	19 940	12.98

Operating with 150 lb. Boiler Pressure, 28-in. Vacuum and 150° Superheat, at 1 800 rev. per min.

8.....	0.479	151.4	27.99	153.7	.....	1 827.4	520.1	7 194	13.85
13.....	0.983	148.6	27.99	153.9	.....	1 827.4	1 066.5	12 580	11.79
12.....	1.24	149.9	27.97	152.2	.....	1 807.8	1 345.8	15 370	11.42
11.....	1.41	149.2	27.76	153.5	.....	1 792.9	1 529.3	17 592	11.5

TABLE 8.—750-kw. Turbine No. 94, Operating with 150 lb. Boiler Pressure, 100° Superheat and 28-in. Vacuum, at 1 800 rev. per min.

Test number.	Percentage of nominal full load.	Throttle pressure, on gauge in pounds per square inch.	Vacuum referred to 30 in. barometer.	Superheat at throttle, in degrees Fahrenheit.	Quality shown by calorimeter.	Speed shown by continuous counter.	Load, in brake horse-power.	Total net pounds of steam condensed.	Pounds of steam per brake horse power-hour.
5.....	0.503	153.2	28	103.46	.....	1 814	545.9	7 884	14.44
6.....	0.928	151.4	27.92	100.6	.....	1 800	1 006.2	13 037	12.96
7.....	1.22	150.8	27.6	100.8	.....	1 782	1 332	17 033	12.78
8.....	1.82	146	26.57	105.8	.....	1 764	1 981.2	27 855	14.06

TABLE 9.—Test of 750-kw. Turbine No. 95.

Operating with 150 lb. Boiler Pressure, 26-in. Vacuum Dry Saturated Steam, at 1 800 rev. per min.

Test number.	Percentage of nominal full load.	Throttle pressure, on gauge in pounds per square inch.	Vacuum referred to 30-in. barometer.	Superheat at throttle, in degrees fahrenheit.	Quality shown by calorimeter.	Speed shown by continuous counter.	Load, in brake horse-power.	Total net pounds of steam condensed.	Pounds of steam per brake horse power-hour.
12	0.485	155	26.12	.....	99.8	1 831	526.1	9 659	18.35
11	0.715	154	26.08	.....	99.6	1 824	776	12 901	16.62
10	1.03	152	26.23	.....	100	1 815	1 125.6	16 958	15.06
9	1.41	152.5	26.09	.....	99.8	1 786	1 535.7	22 629	14.73

Operating with 150 lb. Boiler Pressure, 28-in. Vacuum, Dry Saturated Steam, at 1 800 rev. per min.

7	0.484	155	28.06	.....	100	1 824	525.4	8 385	15.95
6	0.722	151.5	28.01	.....	100	1 826	783.3	11 480	14.65
5	1.029	151.5	28.04	.....	100	1 822	1 115.8	15 355	13.76
8	1.43	152	27.35	.....	99.8	1 792	1 553.3	21 731	13.99

TABLE 10.—Test of 400-kw. Turbine No. 68.

Operating with 150 lb. Boiler Pressure, 100° Superheat and 28-in. Vacuum, at 3 600 rev. per min.

Test number.	Percentage of nominal full load.	Throttle pressure, on gauge in pounds per square inch.	Vacuum referred to 30-in. barometer.	Superheat at throttle, in degrees fahrenheit.	Quality shown by calorimeter.	Speed shown by continuous counter.	Load, in brake horse-power.	Total net pounds of steam condensed.	Pounds of steam per brake horse power-hour.
6	0.483	153.1	28.03	92.5	.....	3561.6	279.4	4 005	14.34
5	0.710	153.2	28.03	102.9	.....	3532.2	410.7	5 522	13.45
4	1.13	152.7	28.03	100.25	.....	3502.8	657.3	8 207	12.48
7	1.34	153.2	28.03	93.1	.....	3486	777.6	9 652	12.41
8	1.67	149.6	27.62	100.2	.....	3460.8	967.5	12 377	12.79
9	2.09	152	27.28	99.9	.....	3454.5	1 207.5	16 365	13.55

Operating with 150 lb. Boiler Pressure, Dry Saturated Steam and 28-in. Vacuum, at 3 600 rev. per min.

12	0.487	154.7	28.07	2.9	.....	3597.3	281.6	4 468	15.86
11	0.717	154.8	28.03	1.8	.....	3571.3	414.6	6 242	15.05
10	1.14	152.6	28.04	2.9	.....	3513.3	660	9 169	13.89
13	1.25	151.6	28.07	0.75	.....	3500.3	725.9	10 060	13.85
14	2.01	150.85	27.02	2.3	.....	3496.1	1 165.6	17 632	15.12

TABLE 11.—750-KW. TURBINE NO. 96, OPERATING WITH 150 LB. BOILER PRESSURE, 28-IN. VACUUM AND DRY SATURATED STEAM, AT 1 800 REV. PER MIN.

Test number.	Percentage of nominal full load.	Throttle pressure, on gauge in pounds per square inch.	Vacuum referred to 30-in. barometer.	Superheat at throttle, in degrees fahrenheit.	Quality shown by calorimeter.	Speed shown by continuous counter.	Load, in brake horse-power.	Total net pounds of steam condensed.	Pounds of steam per brake horse power-hour.
5.....	0.47	147	28	.....	1.0316	1 825	514.5	8 335	16.20
6.....	0.77	144.4	28	.....	0.9766	1 820	844.4	12 139	14.37
7.....	1.03	144.1	27.83	.....	1.0876	1 822	1 128	15 747	13.96
8.....	1.52	139.6	27.17	.....	0.9883	1 786	1 657	23 134	13.97

TABLE 12.—750-KW. TURBINE, NO. 96, OPERATING WITH 150 LB. BOILER PRESSURE, DRY SATURATED STEAM AND BACK PRESSURE, AT 1 800 REV. PER MIN.

Test number.	Percentage of nominal full load.	Throttle pressure, on gauge in pounds per square inch.	Back pressure, in pounds per square inch above atmosphere.	Speed shown by continuous counter.	Load, in brake horse-power.
10.....	1.61	126	9.2	1 754	1 176

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON

STEAM TURBINES.

By Messrs. M. L. Holman, G. O. M. Olsson, J. N. Chester, Charles Hermany, Elmo G. Harris, Charles A. Hague, F. R. Low, Karl P. Dahlstrom, R. N. Ehrhart and Francis Hodgkinson.

Mr. Holman.

M. L. Holman, M. Am. Soc. C. E., St. Louis, Mo.—The speaker has no interest in the Parsons turbine beyond that of an engineer and mathematician. The steam turbine, like any other prime mover, is destined to fill a certain limited field; it will not supplant all other forms of prime movers. The field which the turbine will fill can be determined only by actual use. Tests showing the performance of steam turbines under laboratory conditions will give a very poor idea of their performance in actual use.

The steam turbine seems to be best adapted for high-speed work. The greatest call for that work at present appears to be in and along electric lines; and where the electric load approximates the load and conditions obtained in the laboratory, the results will be similar. Where the electric load is, as it is in a great many cases, a fluctuating load of large degree, the turbine may not prove as successful as the cross-compound or tandem-compound steam engine. That, however, can only be proven by actual commercial use. Under steady loads, the turbine, like the triple-expansion engine, or the compound engine, will develop a much higher steam efficiency than it will under fluctuating loads. Now the best form of steam engine, or the engine which gives the best duty, the triple-expansion pumping engine, would be a deplorable failure in a rail-

Mr. Holman. way power-house, for the reason that the load conditions are not suitable for that form of engine. The turbine, as the speaker has stated, must win its way commercially. The people invest money in steam turbines for the purpose of making money and not for the purpose of advancing science. Now, if the steam turbine will show a better return for the money invested than the compound engine, the turbine will win over the compound engine as a prime mover. If the reverse is the case, the result will be that the compound engine will win out. It is the speaker's opinion, that under power-house conditions, the compound engine will win out in some places and under some conditions of load, and that the turbine will win out under other conditions of load, and each will fill its proper sphere. It is too early at the present stage of development of the steam turbine to predict just what field it, as a prime mover, will fill.

Engineers who have had experience with the actual conditions, as well as a knowledge of the theoretical considerations, will appreciate the point which the speaker is trying to make. He thinks that Mr. Ehrhart will appreciate it; he will if he has ever "stood watch" in a power-house.

To produce a vacuum for a condensing engine, where it is necessary to buy water to make steam—where a surface condenser is put on and a cooling tower is used—only little more water is used than with a non-condensing plant. In other words, very little more water is purchased from the city than where the exhaust is into the air.

Mr. Olsson. G. O. M. Olsson, Esq., Stockholm, Sweden.—The speaker has had several years' experience with the De Laval steam turbine, and from that experience he is able to judge somewhat in regard to other systems of turbines. As to the point brought out by Mr. Holman, that the turbine working under variable loads would probably be inferior to a reciprocating engine, it may be said that it is just in that particular case that the steam turbine will show its superiority. The reason is, to a great extent, that the passive resistance of the steam turbine is very low, and, consequently, the mechanical efficiency is high.

As to its thermal efficiency, it is, so far as the speaker knows, lower than that of a high-class multiple-expansion reciprocating engine; but that low thermal efficiency is not due to the same reasons that cause the losses in reciprocating engines. Those reasons, as all know, are principally due to internal condensation. The losses in a steam cylinder vary with the rate of expansion; they are at their lowest at that degree of expansion for which the engine is constructed. At a higher degree of expansion, the internal condensation increases; at a lower degree, of course, each pound of

steam does not develop the amount of work that it should. These are the reasons why the economy of the reciprocating engine decreases each side of the normal load. The steam turbine, on the other hand, does not have the loss due to internal condensation. It has also been practically proved that if a steam turbine be regulated in the proper manner, the variation in efficiency at variable loads is very small. A De Laval steam turbine running at about half load has been shown to consume not more than 5% more steam per horse power than when running at full load; that is, if the different steam nozzles be shut off to correspond with the quantity of steam used at the reduced load. The present De Laval steam turbine is not provided with an automatic device for closing the nozzles. They have to be shut off by hand. This cannot be done in an electric power station used for running street cars, because the load in that case varies continually, and a man cannot always stand by to close up the nozzles. Consequently, the turbine must, in its present state, run for such work with as many nozzles permanently open as will suffice for the maximum load; and, in order to adapt it for this kind of work, a method of regulating the nozzles automatically will, of course, have to be introduced. Mr. Olsson.

Another question which has been raised, upon which the speaker may be able to give some information, relates to the economy of superheated steam. Theoretically, the gain derived from the superheating of steam depends upon the circumstance that the extra heat put into a certain quantity of steam, after it has been saturated, increases its volume. Consequently, if worked in a cylinder, where the dimensions are proportionately increased, the superheated steam will give a larger surface to the indicator diagram than the same quantity of saturated steam. Working out theoretically from that principle, the amount of gain in work per pound of steam introduced by superheat is found to be a variable quantity, according to the rate of expansion of the steam. The benefit of superheating is greater in the case of a high-pressure engine, in which the steam expands down to one atmosphere, absolute pressure, than it is in a condensing engine, where the expansion is carried down to one-tenth of an atmosphere. Calculating upon the latter engine, it is found that 100° cent. of superheat will give, theoretically, about 13% less consumption of steam per horse power, not taking into account cylinder condensation and such sources of loss as cannot be determined by theory. Taking degrees Fahrenheit as a base, it will be found that there is about 7½% gain in the work of each pound of steam per 100° superheat. This gain is, moreover, proportionate to the degree of superheat; so that, if a curve is worked out, in which the abscissas represent the degrees of superheat, and the ordinates indicate the saving in steam consumption, a straight line will be the result.

Mr. Olsson. Now comes the question, which is of greater importance, namely, the saving of fuel. Superheated steam is more expensive to generate than saturated steam, and this reduces somewhat the gain which has been referred to, and, theoretically, it is cut down by a little less than one-half. It may be said that of the 7½% saving in steam, which 100° superheat brings about in a condensing machine, about 3% will be neutralized by the greater consumption of coal per pound of steam, consequently 4½% net gain in fuel will be theoretically the advantage of superheating by 100 degrees.

The gain stated as that which the superheat will bring about is worked out theoretically on the basis that the volume of steam increases, in a certain degree, when it is superheated. Now the gain, which practically is obtained, depends upon the class of engine used. In a low-grade engine, the actual gain will be greater than the theoretical, because the superheat not only imparts a greater volume to the steam, so that it can fill a larger part of the cylinder, but it also does away with the internal condensation. In a high-grade engine, where the internal condensation is very low on account of well-arranged steam jackets, insulation, etc., it is shown by practice that the gain comes very near to the theoretical figure, as it also does in the steam turbine, this type of engine having no internal condensation. The tests of steam turbines working with superheated steam show that the gain is very near the theoretical figure just mentioned.

Speaking of steam turbines, the point which the speaker maintains is that the saving of steam is about equal to that which can be theoretically worked out. The same is shown to be the case in a high-grade steam engine by tests that were made some time ago at the works of the firm of Van den Kerchove in Bruxelles. Those tests were not conducted by the firm, but by two gentlemen, one of whom was Mr. Vincotte, Chief Inspector of the Boiler Inspection Society of Belgium, and the other Professor Schröter, of Münich, Germany, a gentleman whose name has been associated with a great number of engine tests. These gentlemen carried out their tests at different times, a month apart, and they came to practically the same results; their results differing only about 2 or 3 per cent. They tested the engines running at various loads and with various degrees of superheat. Mr. Vincotte carried the superheat to a temperature as high as 400° cent., which is something like 700° fahr. It was found that when the engine was running at its most economical load, the saving of steam realized by the superheat was very near the theoretical value. These tests, moreover, demonstrated that the saving was proportionate to the degree of superheat. When the engine was not working at its best load, there was some difference between the calculated and the actual gain, although it was not very material.

Mr. Olsson.

There is some question as to the applicability of steam turbines in factories. In Europe there are a great number of steam turbines used in factories. The De Laval steam turbine was geared down, from the time it was first put on the market, to such an extent as to allow it to be used for belt-driving; a good many 300-h. p. steam turbines of this type are at the present time driving belts or ropes in factories. The safety of the De Laval turbine is well provided for. There is, in the first place, a very sensitive centrifugal governor that governs by throttling the steam pressure. If that governor should prove to be inadequate, there is a safety device which breaks the vacuum, in the case of a condensing engine, causing the speed to slow down. In the case of a non-condensing engine, it is impossible for the steam to drive the wheel up to such a speed as to break it. Supposing that, in a condensing engine, both these governors should fail at the same time, there is still the following safety device: Close to the rim of the turbine wheel there is a weak part, which causes the rim to break off when the speed of the engine is increased to a certain extent, thus preventing any rupture in the body of the wheel. The portions that are detached from the wheel rim are not large enough to damage the box, so that the damage will not extend beyond the breaking of the rim of the turbine wheel, which simply necessitates the comparatively simple and cheap operation of putting in a new wheel.

Mr. Chester.

J. N. Chester, M. Am. Soc. C. E., Pittsburg, Pa.—The speaker has noted the abandonment of reheaters in connection with turbines, but never really understood the reason for it. So far as reciprocating engines are concerned, he can only cite a very pointed instance in an engine tested recently, where the horse-power requirements were that it deliver 6 000 000 against a certain number of pounds discharge pressure with 100 lb. of steam. This engine was fitted with reheaters, being of the six-cylinder compound or low-duty triple type; and on the morning of the test, one of the reheaters was found to be leaking; all were cut out. The engine could not be gotten to speed with its contract steam pressure, do what the experts would. But at a subsequent test, after the reheaters were repaired, the contract speed was readily obtained, where, without reheaters, it fell 12% below.

Mr. Hermany.

Charles Hermany, President, Am. Soc. C. E., Louisville, Ky.— As a prime motor, the reciprocating multiple-expansion steam engine has ranked the highest of all prime motors for a majority of uses. The steam turbine has come; and in order to equal or rival the reciprocating steam engine, practically or commercially speaking, it must demonstrate not only its availability and special adaptation for use, but also its superior economy. The speaker would ask Mr. Ehrhart to state what progress the steam turbine has made

Mr. Hermany. in that direction, that is, to equal, rival or supplant the reciprocating steam engine commercially.

Prof. Harris. ELMO G. HARRIS, M. AM. SOC. C. E., Rolla, Mo.—There seems to be no room for doubt that steam turbines, under tests by the manufacturers, give excellent results. But are the manufacturers prepared to give assurance that such machines will operate efficiently, be safe and enduring under ordinary service and when trusted to the ordinary mechanic?

What will be the nature and extent of the damage, if the oil fails to run for a few minutes? How will the bill for repairs in ten years of operation compare with that for a good reciprocating engine giving equivalent service?

Such questions are of as much importance to a prospective purchaser as that of thermal efficiency, and the manufacturers must be prepared to answer these questions satisfactorily before they can hope to introduce the steam turbine very generally.

Several years must pass before we can say that these questions are answered, but they should not be ignored in any discussion of the merits of a new machine.

Mr. Hague. CHARLES A. HAGUE, M. AM. SOC. C. E., New York City.—In the first place, there is some excuse for going into elementary talk upon this subject of steam turbines, because it is comparatively new. And, following that line, it will no doubt help the mind somewhat to look at the distinctive difference between the principles of reciprocating steam engines and those of turbine steam engines. Now when a boiler has steam up and a pipe connected to a reciprocating steam engine, the throttle is opened and the expansive force of the steam fills the cylinder and pushes the piston along. When the cut-off is used at any certain point in the stroke, the steam by internal expansion, so to speak, forces the piston along in the same manner. If a block is put across the fly-wheel of a reciprocating engine so as to prevent it from turning and so the wheel cannot move, and the throttle is then opened, nothing will take place; no steam is used; nothing gets away. But, on the contrary, the turbine steam engine, like the turbine water-wheel, is a reactionary machine. In the water-wheel, the water above the wheel is at one level, and the water below it is at another and a lower level; the water possessing the potential energy due to the difference in level of the head and tail waters. Upon the opening of the gate, the water seeks the lower level and then, in trapping it and passing it through the wheel, the water is made to pay toll in the form of power. The same way with the turbine steam engine. The steam is taken at a very high pressure, and by having a vacuum at the other end of the machine the steam is passed through the turbine and made to pay toll in the form of power. But, contrary to the reciprocating steam

engine, if the mechanism of either the turbine water-wheel or the turbine steam engine is blocked, and the water-gate or the steam throttle opened, the water in the head-race or the steam in the boiler will escape, and yet no work will be done. This radical difference in principle indicates that entirely different lines of thought must be followed, as between the reciprocating engine and the turbine. Mr. Hague.

Following out this thought, the impression upon the speaker's mind is, from what he has been able to hear of turbines, although having had no actual experience with them, and no other knowledge of them than that obtained by a good many years of steam study and experience, that associated with the turbine is the idea of a rather high superheating of the steam at one end of the apparatus, and a vacuum as high as possible at the other. The operation of the turbine under ordinary conditions, and under what are generally called commercial conditions, does not seem to be discussed very much; and further the mechanical application of power seems to be the ruling factor, with a desperate effort to equal the steam economy of the reciprocating engine as an accompaniment. The definition of the word, accompaniment, is "something that attends as a circumstance, or which is added by way of ornament to the principal thing, or for the sake of symmetry."

There is no special objection to this superheating factor if it really pays, but we are confronted by a statement to the effect that superheating from the standpoint of the plant is a doubtful factor; which simply means that although superheated steam after it has been obtained is economical, when the cost of obtaining it is entered into the total calculation, there remains a doubt as to the ultimate economy of the application. If this is so, and if the cost of superheat is not justified by the plant economy, but if it must nevertheless be used because the delicate blades and vanes of the turbine do not act freely with ordinary commercial steam, then the cost of superheat must be honestly charged up against the machine, and its mechanical advantages regarding electrical adaptability, and possibly, although not proven, marine driving, must go to its credit to ascertain exactly where the account stands as a whole. In other words, it seems to be necessary to go to a supplemental effort to put the steam into a condition which the turbine at least desires, not to say, demands; and at the other end of the apparatus there is a call for a high vacuum, a vacuum so high in fact that it goes to an extreme which in a great many cases, especially in marine work, has been considered unprofitable, as reducing the terminal temperature to too low a point. And as above intimated, whether putting the excessive heat into the steam and then cooling down the terminal pressure to such a low point, whether those apparent disadvantages can be practically met in some other way, may

Mr. Hague. of course remain to be determined. It certainly is to be determined, and in this connection it may be well to say a word about what is called the "commercial value." It seems to the speaker that the words, "commercial value," are often used in an improper sense. "Commercial value" simply means the covering of all the conditions. It is just as incumbent for the engineer to know what the conditions are, as it is for the business man to know what conditions must be met. Engineering is the art and science of producing effects which are beneficial and profitable to the human race; and of course it will not do to sacrifice, to an unreasonable extent, one item for the sake of furthering another unduly. So that when the words "commercial value" are used, they simply signify the real value, taking all conditions into the account, and not one condition, or one set of conditions.

It will be noticed in Mr. Hodgkinson's paper that most of the tests have been made with superheated steam and into a pretty high vacuum. At Pittsburg the elevation above the sea is considerable, so that a 28-in. vacuum is very high for that point, but it is understood that this vacuum is referred to a 30-in. barometer or to sea level, which ought to mean that the vacuum was not really 28, but would have been 28 if the experiments had been made at sea level. The question of vacuum brings into the matter the further question of condensers, and there are a great many steam plants where it is very inconvenient, not to say impossible, to use condensers; it is an absolute axiom that it does not pay to buy water for the purpose of saving coal for the simple reason that the coal saved is worth far less than the water bought, and, under ordinary circumstances, would be upon the basis of about $1.30 worth of coal saved at an expense for condensing water at 5 cents per 1 000 gal. of about $2.26, if bought from the water-works. All of which indicates the impracticability of buying water to effect condensation so as to increase the steam expansion and so to economize in cost of power. This is one of the items going into "commercial" results, which it is the business of the engineer to consider purely from an engineering standpoint. The cooling tower, as introduced into modern practice, will modify the water question in some localities and with plants of sufficient capacity to justify its installation, although this will, of course, increase the capital account and call for interest and depreciation charges. But with all that the cooling tower can do to help out the situation, there will be many plants where its use would not be practicable from several standpoints; and there are many contemplated plants and many already in existence where superheated steam will not be readily procurable. But of course the future must be provided for, although those plants already in existence must be gotten along with, and conditions may gradually work round to a

point favorable to some things which at present do not seem to be very near. Mr. Hague.

The tests with non-condensing conditions and with dry saturated steam show a steam consumption of 28 lb. per h. p-hr., and with non-condensing, superheated steam, 23 lb. per h. p-hr. But a reciprocating engine with dry saturated steam at 150 lb. pressure will produce a brake horse-power with 18 lb. per h. p-hr., and the capitalized coal account under such a difference would go a long way toward paying for the latter engine; allowing 8 lb. evaporation, 28 lb. of steam would require 3.5 lb. of coal per h. p-hr., and 18 lb. would require 2.25 lb. of coal per h. p-hr. This difference at 10 hr. per day and 300 days to the year, capitalized at 13% for interest, depreciation, etc., would represent $43 269.23 with coal at $3 per net ton, or $28 846.15 with coal at $2 per net ton. The above for 1 000 h. p.

Taking the tests with 28-in. vacuum, with about 150 lb. steam pressure and from 100 to 150° superheat, an average of the best record of six tests gives 12.54 lb. of steam consumed per h. p-hr. by the brake. The highest type of triple-expansion pumping engine would reduce this record, at least 2 lb. per h. p-hr. figured from the pump end, which would be equivalent to the brake power, so that from a steam-engine standpoint, we have the following comparison:

Brake, or pump horse power	1 000	
Steam pressure	150	lb.
Vacuum	28	in.
Superheat	100°	fahr.
Turbine, steam, horse-power hour	12.54	lb.
Reciprocating, steam, horse-power hour	10.54	"

The turbine is brake horse power.
The reciprocating is pump horse power.

At 8 lb. evaporation, the difference in coal at $3 per net ton will pay 13% on $25 261.53, or 5% on the sum of $65 700; this with both types of prime mover at their best, regardless of what may have been the cost of the superheated steam.

With dry saturated steam the showing is as follows:

Brake or pump horse power	1 000	
Steam pressure	150	lb.
Vacuum	28	in.
Dry saturated steam,		
Turbine, steam, horse-power hour	14	lb.
Reciprocating, steam, horse-power hour	11	"

The turbine is brake horse power.
The reciprocating is pump horse power.

Mr. Hague. At 8 lb. evaporation, the difference in coal at $3 per net ton capitalized at 13% amounts to $37 903.84, or capitalized at 5% amounts to $98 550; this with the turbine at the five best records in the paper under discussion.

The above comparison places both the turbine and the reciprocating engine in their very best spheres of usefulness regarding steam economy. Perhaps the reciprocating engine would suffer when both are compared in the electric field, although this has been by no means proven up to the present time, except under special conditions. The turbine would certainly suffer by comparison in the water-works field, as may be shown by the possibilities so far available, inasmuch as it is altogether improbable that the efficiency of the turbine steam engine is 100%, and even that would not save it. In the absence of practical evidence, it will at least be fair to the turbine to give it credit for 98% efficiency, although this is quite likely to be too high by several points. The use of the turbine steam engine in water-works would, of course, be coincident with that of the turbine pump, the two mechanisms fitting each other admirably, especially with reference to speed and angular effort, the word, effort, being used advisedly. Then if the efficiency of the turbine pump is, say 75%, the net efficiency of the completed turbine pumping engine would be 73.5%, as against 96% mechanical efficiency of the reciprocating machine. This means that the reciprocating machine will do 32% more work with the same steam, and this means 14.52 lb. of steam per pump horse-power hour for the turbine apparatus, and 11 lb. per pump horse-power hour for the reciprocating machine; which, capitalizing the difference in coal at $3 per ton, at 13%, amounts to $44 473.84, at 10%, to $57 816, and at 5%, to $115 632, with the evaporation taken at 8 to 1, and the pump horse power at 1 000, which is the probable unit for the near future, in fact, it is closely approached at present. Even at this, it would be very rash to put the turbine at anything but reservoir work from what it has so far shown.

If the turbine proves itself superior in the future, in the pumping, or any other field, it will most certainly take its place and nothing can stop it from doing so; it will simply be relegated to where it can be best utilized in the long run or under special conditions. But before it is decided where it can be used best, the conditions must be looked into, and the "commercial" status of the machine established, which will come in good time.

The range of efficiency shown under varying loads, the speaker considers extremely satisfactory in a turbine or any other form of steam engine. In Table 6 of the paper, the range of load is from 354 to 2 146 h. p., or an increase from low to high of 600%, and yet the steam consumption only varied from 15.32 to 13.91 lb. of steam

per h. p-hr., although the total steam used varied from 5 439 to 29 874 lb. Mr. Hague.

Speed regulation is another factor of importance in prime movers, and although the highest speed given in Table 6 is only 2% above the lowest, from the fact that decimals appear in the record up to two places in the speed log, it may be judged that these figures are averages and do not disclose what variation from high to low may have taken place. In cotton and flour mills, uniform speed is imperative for the finest goods and most profitable results, but the load is quite steady, as regards variation, in demands for energy; still the uniform rate of rotation is paramount. If the turbine can be governed so as to produce these steady speeds, its high rate of revolution will be decidedly in its favor. In planing mills, the cutter heads sometimes run as high as 5 000 rev., the speaker having known cases where 5 500 and 6 000 rev. have been reached. It seems certainly advantageous to have the prime mover start off at several thousands per minute. But after all that has been said and done, it looks to the speaker as if there were still considerable to be accomplished, and several important questions to be answered, among them:

What will it cost to superheat the steam?
What will be the efficiency with 2% entrainment?
How high a vacuum can be practicably maintained?
How far will it pay to go into high vacuum?
How far will the steam auxiliaries reduce the apparent economy?
What will be the cost in money of the power at the switchboard?
What will be the cost in money of water per million gallons pumped?

There are other points not occurring to the mind at present, but which naturally will at some time or other, and no doubt it will be felt and expressed by buyers and users of power that there is need of bringing, as speedily as may be, this promising motor down from the realms of theory, where some important points may be overlooked, to a rational and practical plane where it must stand or fall upon its merits, unaided by the powerful impetus it is now likely to receive from great capital and energy interested in it in a business sense. And this is not said with any disparagement of theoretical considerations; far from it. Theory is the law of fact and must not be confounded with hypothesis, but theory must cover substantially all the facts.

Those high up in the field of steam turbineism are not able to say what the commercial gain is by the use of superheated steam, and send the question back to the business man for solution, and, of course, the business man will look very attentively at the cost of the horse-power hour, regardless of either hypothesis or theory, but

Mr. Hague. with a very serious regard for facts. Further, considering the other extreme of the problem, the question is not how high a vacuum is it possible to get, but how high a vacuum will it pay to get? It is possible to get and carry 29.5 in. at sea level, and, in proportion, in any locality; but the curves of cost and profit will cross somewhere. The turbine people are looking very closely and perhaps anxiously at the vacuum item, but it is an old story, and they will no doubt locate its value in due season.

In the details of this discussion, there has been raised the question as to what would be the economy of a triple-expansion steam engine of the reciprocating type capable of giving an indicated horse power upon 12½ lb. of steam per h. p-hr., if suddenly turned over to run non-condensing. This question has been brought up by the consideration of a turbine represented by the tables in this paper, built for a condensing machine, but run non-condensing and giving a horse-power hour for 28 lb. of steam. The question is would the reciprocating machine do better than 28 lb. with the immense area of condensing cylinders?

It most assuredly would do better than 28 lb. The high ratio of expansion into a vacuum, when running condensing, would be immediately reduced, and the cylinders would be very much hotter under the lower ratio and higher steam pressures throughout the stroke; the steam consumption would, of course, rise, but most likely not above 19 lb. per h. p-hr. But after all this would only be an engineering trick, because practically and from a "commercial" standpoint no such conditions would appear, or if they did appear, it would only indicate that a new chief engineer was needed.

Referring to the question as to whether or not a steam turbine running non-condensing would be a commercial proposition at 22 to 23 lb. of steam per h. p-hr., the speaker is of the opinion that there is no steam turbine capable of giving a horse power with so small a consumption of steam as 22 to 23 lb. per h. p-hr. Probably 28 to 30 lb. is a low record under ordinary conditions, and, allowing a reduction of steam used at the rate of 1% for each 15° of superheat, with 150° superheat, the steam consumption would likely be in the neighborhood of from 25.2 to 27 lb. per h. p-hr.; and by the same advantage of superheat in the reciprocating non-condensing compound, the steam would no doubt be as low as 19 to 20 lb. per h. p-hr. The turbine engine might be run at less first cost, but if the difference in fuel were capitalized upon, say, 1 000 h. p. and at 8 lb. evaporation under actual working conditions, the difference in coal at $3 per net ton would pay 10% on $36 000, or 5% on $72 000, and, under ordinary conditions of steam, the difference would be a little more in favor of the reciprocating engine, but not much unless 2% entrainment crippled the turbine considerably. From the

foregoing it will be seen that the turbine non-condensing steam engine has yet to prove its cost as a commercial proposition, especially as the turbine people themselves say that the cost of superheat with reference to commercial value is still an unknown quantity. Therefore, it would seem that the steam turbine was as yet an extremely interesting fad, something like the bicycle and automobile, destined after much trial and tribulation to take its place in the onward march of time. Mr. Hague.

As to the regulation of speed, the steam turbine is no doubt quite satisfactory, although it has been stated that from 3 to 4% from no load to 100% overload is about the result obtained. The reciprocating engines from no load to full load range just about 3%, not over that in good practice. The regulation of the Parsons turbine in marine service can hardly be taken into account, because the enormous mass of the steamship comes in as a part of the regulating force, a mass which of course cannot be changed at all as to velocity; so that as long as the wheels are submerged, the turbine at sea is held safely. With an electrical outfit, with the heavy revolving parts under high velocity, there is an enormous amount of fly-wheel momentum, and the output in lighting is either small or gradual in its changes, while in railroad work the changes are of a character which affects the economy of the machine rather than the quality of the product. But in factory work, where there are considerable variations in power with a demand for very close uniformity of speed, with the use of delicate machinery, such as is used for spinning the finer grades of yarns, etc., there is an entirely different problem, and it is a field into which so far the turbine has not gotten to any great extent.

There are several questions which might be catalogued as consumers' or users' questions, which might be well raised here. Those who are looking for satisfactory machines are apt to ask such questions as, how safe is this machine in the hands of untrained mechanics? Or, at any rate, mechanics who have had no training in the shops of the manufacturers? There are certain good machines that give good results in the hands of those who are familiar with them; but are the manufacturers now ready to deliver turbine steam engines to outlying towns in New Jersey or Missouri, or any other State or locality, and say that they will endure under the treatment which they will probably receive?

In other words, are these machines danger-proof to a reasonable extent? If not, what is the extent of the damage when somebody fails to keep the oil going? What is to be the result? How long will they endure under reasonable service? And when they give out, to what extent do they give out? How about the centrifugal force under such high velocity? Who pays for possible accidents?

Mr. Hague. There are other questions which suggest themselves, but the foregoing are some that have been brought out in this discussion, and of course are brought out by the contemplation of something new and, to a great extent, unknown; brought out as well no doubt by those contemplating the use of such machines if they can be demonstrated to be satisfactory to the user. Regarding these questions, the speaker will say that he is not a manufacturer, but has been associated with manufacturers and has seen a good deal of them, and it hardly seems necessary, even with a steam turbine, to send out an accident insurance policy with each engine, or any other apparently well-established machine. When the immense capital and responsibility back of these machines are considered, it hardly seems necessary to worry very much about their safety and the consequences of using them.

Mr. Low. F. R. Low, Esq., New York City.—Bearing upon the possible damage from the running away of a turbine, a case in point is the recent accident at the Fisk Street Station in Chicago, where one of the 5 000-kw. machines ran away. By reason of some electric disturbance, the system into which it was delivering, backed through and motored the big machine until it ran up to such a speed as to destroy the electric end, without, as the speaker understands it, damaging the steam engine at all. Perhaps Mr. Ehrhart will tell of a similar accident at the Yale and Towne Works, where one of the Parsons machines, by reason of the failure of the electric end, ran away and did no damage at all to the steam end, or the surroundings.

Mr. Dahlstrom. Karl P. Dahlstrom, Esq., Stockholm, Sweden.—In regard to the necessity of having a skilled man to run a steam turbine, the speaker desires to state that he is connected with the management of a traffic company in Sweden having a repair shop where a De Laval non-condensing steam turbine is used with a dynamo for the generation of electricity for lighting not only the shops, but also an office, dwelling-house and stations in the vicinity, the exhaust steam being used in the winter for heating purposes. It is a 50-h. p. non-condensing turbine, purchased in 1900, and has been running nearly every night since, giving entire satisfaction. No skilled engineer is employed to run this turbine, but only men who have barely knowledge enough to run an engine and boiler. Not only that, but these men are constantly changing, belonging as they do to a class of help who, for the task in question, can be depended on only for a few months at a time. No trouble has ever been experienced with this engine; once only a bearing, from some neglect of the tender, got hot and wore out, so that a new one had to be put in, which was easily done, because the factory keeps interchangeable parts. For oiling, a high grade oil must be used. From the speaker's experience

he can heartily commend this steam turbine to those who desire an engine, the first cost of which is low, in places where the highest steam economy is not a prime consideration. Mr. Dahlstrom.

R. N. EHRHART, ESQ., East Pittsburg, Pa.—The steam turbine is fortunately not subject to the limitations which, in the case of some prime movers, render satisfactory operation under widely fluctuating loads extremely difficult to attain. Speed regulation is largely enhanced by the high rotative inertia of the turbine, which inherently operates to dampen or absorb the sudden changes in impressed torque on the turbine shaft. Furthermore, no cyclical speed variations which constitute so important and so difficult a problem in piston-engine work are present. The steam turbine is an engine in which the theoretically correct design for maximum loads varies by no great extent from that for fractional loads, so that its economy at fractional loads is necessarily good. Table 6 will illustrate this point. From two-thirds of full-rated load to practically double load, the steam consumption is less than 14 lb. per brake horse power per hour, and for a wide range of load it is well under 13 lb. These characteristics are amply verified by numerous other economy tests under similar conditions of load, and indicate that the turbine is well suited to power service such as is encountered, for instance, in modern street-railway work. Mr. Ehrhart.

Superheat is unquestionably an important factor in the attainment of the highest turbine as well as the highest engine economy. In approximate figures, 100° fahr. superheat will reduce the steam consumption of a Parsons type turbine by 10 per cent. The net or commercial saving, however, reduces the saving considerably, owing to the cost of supplying heat to the superheater, the capital and depreciation charges on the apparatus, and extra labor involved. Although many plants, both in the United States and abroad, use superheated steam, the question of ultimate commercial effectiveness still remains at best an open one.

Intermediate reheaters have proven, in turbine as in engine work, of questionable commercial value. By adding heat at a lower temperature the efficiency of the cycle is reduced. Other losses are, however, compensated for. The net result is much in doubt, and, at best, the gain is so small that the added complexity, bulk, and cost of construction are not warranted.

The specific heat of superheated steam does not enter directly into results obtained on the testing floor, as only tangible quantities are measured—power developed and steam consumed. The long accepted figure, 0.48, still remains in force for conditions approximating atmospheric pressure and saturation. Late experimenters appear to have discovered a departure from this figure for higher pressures and superheats.

Mr. Ehrhart. To assign to turbine or engine a position of definite superiority is an almost impossible task. Superficial comparisons are valueless, and it is only through a consideration of capital costs, maintenance, attendance, supplies, and general convenience and reliability, in addition to operative economy, that a proper basis for comparison may be established. The unqualified success that has been attained by the turbine speaks for it more eloquently than words.

In regard to high vacuum and its commercial value, it is customary with vacua observed at high altitudes to reduce to sea-level conditions, or approximately 30 in. mercury; this is done in all tests made at East Pittsburg. The commercial value of vacuum, as has very properly been pointed out, involves not merely an inherent increase in economy, but also considerations of capital cost, maintenance, etc., which also enter into the commercial value of superheat. Where condensing water is available in moderate or even limited quantities, high vacuum is usually profitable. With a properly designed and operated condensing system, a vacuum within 2 in. of the barometer is readily attained, and even higher where conditions are particularly favorable, such as tide-water sites with unlimited water supply of low temperature. To be sure, a high vacuum system requires a definite expenditure of power and consequently costs money, but a well-proportioned system generally insures a large return outside of both fixed and operating costs. In a surface condenser plant, where a somewhat greater quantity of circulating water has to be supplied than in a jet system, the power requirements may be reduced to an extremely low figure by discharging the water at about the same level as the suction, so that power is required simply to overcome fluid friction in the circulating pipes and condenser passages. As the velocity of the circulating water is low, this work is necessarily but a small part of the power developed by the turbine. The dry vacuum pump should not require for driving, more than a fraction of 1% of the full load turbine capacity.

No particular type of condenser may be said to be specially suited to turbine work. The surface type is most generally used in spite of its high first cost, as it enables the entire condensation to be returned to the boilers and the steam cycle maintained free from impurities. The barometric type is in favor for central condensing plants. It may readily be located out of doors and is moderately low in first cost and simple in operation. The ejector condenser opens up a wide field: its simplicity, extremely low first cost ($1.50 per h. p.) and small bulk, make it particularly applicable to steam turbines. One Westinghouse-Parsons plant, equipped with them, regularly maintains 28-in. vacuum with the expenditure of about 1.8% of the full load power of the turbine.

A comparison has been made between engine and turbine unfavorable to the latter in regard to its non-condensing economy, in in which the terms, indicated horse power and brake horse power, the former relating to the engine and the latter to the turbine, seem to be confused. Turbine economy is invariably expressed in terms of useful work—brake horse power, electric horse power, or kilowatts—and engine economy should, therefore, be decreased by 10 to 15% in order to draw comparisons with turbine economy measured in brake horse power. Secondly, the non-condensing results given refer to a turbine designed for high vacuum, but without any change whatever, operated against 15 lb. back pressure, which condition is liable to arise in practice due to accidental breaking of the vacuum. Where designed particularly for non-condensing operation much better results may be secured, as in an engine designed with proper cylinder proportions for atmospheric pressure. Table 6 illustrates this point. Mr. Ehrhart

Close speed regulation, as previously pointed out, is an inherent characteristic of the turbine, due to its high rotative inertia. In electrical work, this manifests itself in the remarkable ease with which turbine-driven A. C. generators operate in parallel, or electrical synchronism. The speed regulation generally specified falls within the range of 2 to 4%, and this is easily accomplished by the turbine from no load to double load.

As brought out by Mr. Low, the accidents at Chicago and Stamford certainly bear witness to the inherent strength of turbine construction. The accident at the Tale and Towne Works was fully explained at the June meeting of the American Society of Mechanical Engineers, and was conceded to be due to a hidden flaw in the generator field forging. The mere fact of high rotative speeds in steam turbines should occasion no apprehension, but rather attention should be given to the linear speed of the several parts and the internal stresses resulting. In a Westinghouse-Parsons turbine operating at 3 600 rev. per min. the maximum stress is about 12 000 lb. per sq. in., which gives a factor of safety of at least five and possibly seven.

Common sense and ordinary mechanical skill are the prime necessities for a turbine operator. If he can run an engine properly, he certainly can run a turbine; but if incompetent for engine work, a certain risk is involved in placing him in charge of a turbine, depending upon his carelessness or inattention to duty. As a rule turbines are "left to themselves" to a considerably greater extent than is possible in engine work. Familiarity with its characteristics does not necessarily breed contempt, but does, unfortunately, induce a somewhat similar phenomenon—a lapse from respect.

Francis Hodgkinson, Esq., East Pittsburg, Pa. (By letter.)— The writer is in thorough accord with the trend of the discussion Mr. Hodgkinson.

Mr. Hodgkinson. in pointing out that the success of an engine does not depend upon its test performance, but rather upon its all-round commercial efficiency, its operativeness, and the cost of repairs, and it is along these particular lines that the type of turbine described in the paper will bear investigation. Its economy at light loads makes it also a desirable unit where the load is very variable.

Mr. Hague makes some comparison between the tests quoted in the paper and some tests of a high-grade triple-expansion pumping engine. Such results are not to be attained by reciprocating engines used for power purposes, and it is in the latter field that the turbine largely finds it place. Mr. Hague also makes a statement regarding the performance of a reciprocating engine designed for condensing but operated non-condensing.

If a triple-expansion engine of high-cylinder ratios, and one such as would produce a brake horse power on 12.5 lb. of steam superheated 100° fahr. per hour, were operated in this manner, its economy would, in the writer's opinion, be nearer 28 lb. per brake horse power hour and would be nowhere near the 19 lb. quoted by Mr. Hague. The turbine under discussion, it will be remembered, gave a result of 23 lb. per brake horse power hour under these conditions.

It is a fact that condensers in power plants are occasionally inoperative from a variety of causes, and it is a contingency to be reckoned with, that condensing engines must occasionally operate and give service operating non-condensing.

In reply to Mr. Chester, the writer desires to state that reheaters have been used in conjunction with the Westinghouse-Parsons turbine, but were abandoned because no gain in economy was found due to their use. If the reheating could be performed by some cheaper method than by condensing high-pressure steam, it would then be worth while.

The value of a reheater is somewhat in question even with reciprocating engines, although the writer believes it is generally recognized that a reheater will much increase the power. Tests have shown that reheaters become of less value as the speed of the engine increases.

It occurs to the writer that these facts may account for the failure of the engine, cited by Mr. Chester, to come up to speed without the reheater.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DEEP FOUNDATIONS.

Congress Paper No. 63.

CYLINDRICAL FOUNDATIONS FOR A QUAY WALL IN THE HARBOUR OF DELFZYL.

By W. F. Druyvesteyn, Engr., Corps of Waterstaat,
Flushing, The Netherlands.

Discussion on the Subject by

O. E. Mogensen, St. Louis, Mo., U. S. A.
K. E. Hilgard, Zurich, Switzerland.
W. F. Druyvesteyn, Flushing, The Netherlands.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 63.

DEEP FOUNDATIONS.

CYLINDRICAL FOUNDATIONS FOR A QUAY WALL IN THE HARBOUR OF DELFZYL.

By W. F. Druyvesteyn.*

In 1902 and 1903 a quay wall founded on brick cylinders sunk to a great depth, was built in the harbour of Delfzyl. This harbour is situated on the River Ems in the northeastern part of the Netherlands, almost opposite the German harbour of Emden.

In connection with the construction of a new railway between Zwolle and Delfzyl (the "North Eastern" local railway), the Government of the Netherlands is making alterations in the harbour of Delfzyl, in order to make it suitable for deep-drawing ships.

In Fig. 1 the situation of the harbour is shown. The works on the side of Delfzyl are now being carried out; the quay wall on cylindrical foundations is finished.

The dotted lines show a project for further extension on the side opposite the town.

The quay wall was to have such dimensions that the largest vessels, which can go up the River Ems, to the harbour of Delfzyl, can be loaded and unloaded. The maximum draft for a ship going through the Ems to Delfzyl is from 30 to 33 ft. It is therefore necessary that the harbour in front of the quay should be deep enough

* Engr., Corps of Waterstaat, Holland.

to prevent such a ship from grounding during low tide. A depth of 36 ft. below N. A. P.* is therefore required. This depth has not yet been obtained. At present the depth of the harbour in front of the quay is 28 ft. below N. A. P.

The quay wall had to be built in the outer harbour, and in a portion of the existing harbour, to a depth of 10 ft. below N. A. P. It was not considered advisable to enclose this part by dikes and excavate a deep foundation pit, for fear that the adjacent sea-dike might give away. A foundation of piles, generally used in the Netherlands, was not practicable owing to the occurrence of pile worms in the harbour.

It was therefore decided to fill up the site with sand to just above low-water mark. This filling served as a base on which the foundation was erected, and after the completion of the quay the sand which lay outside the wall was dredged away. From 10 to 23 ft. below N. A. P. there was a layer of very soft mud. This layer had to be dredged away and sand substituted.

From various plans for the construction of the foundations of the quay wall in this sand filling, the cylindrical foundations were chosen.

For cylindrical foundations brick rings or wells are excavated on the inside, in such a way that the well sinks into the ground by its own weight while the top is being added.

This method can be used only in ground which is homogeneous and in which no boulders or hard objects occur. Should the "shoe" or curb of a well strike a hard object, there is a possibility that the well might list. This is still more to be feared when the soil is irregular. When the soil to the right of the well is softer than that to the left, the well sinks, by its own weight, quicker on the right side than on the left side. In such a case it is often very difficult to replace the well in the proper position.

The tilting of a well, however, is only to be feared at the beginning of the sinking. As soon as the well has sunk perpendicularly to a certain depth, there is not much danger that it will afterwards diverge from the perpendicular. Owing to the friction of the soil against the walls, the well is suspended, as it were, in the soil, and rests on the shoe only to a slight extent. A

*N. A. P. is a level 1.35 m. or 4 ft. 5 in. above half tide at Delfzyl. Ordinary high tide being 1.10 m. or 3 ft. 7 in. above N. A. P., and ordinary low water 1.60 m. or 5 ft. 3 in. below N. A. P. at Delfzyl.

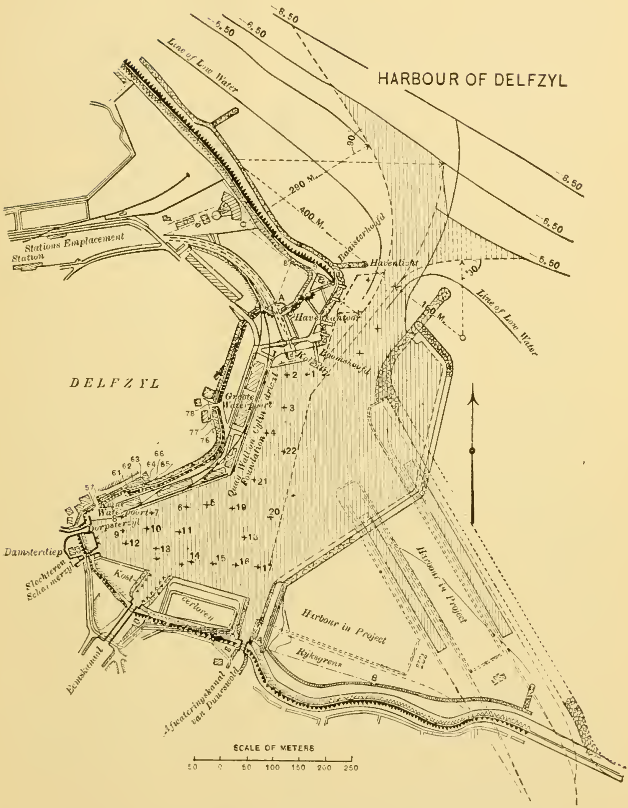

HARBOUR OF DELFZYL
DELFZYL
Line of Low Water
Stations Emplacement
Station
Havenlicht
Havenkantoor
Groote Waterpoort
Quay Wall on Cylindrical Foundation
Damsterdiep
Harbour in Project
Rijksgrens
Eemskanaal
Afwateringskanaal van Duurswold
SCALE OF METERS
50 0 50 100 150 200 250

FIG. 1.

boulder met with at this stage, although it would interfere with the sinking, would not cause an uneven settlement.

The subsoil at Delfzyl is very uniform and was very suitable for the use of cylindrical foundations. The borings which were made showed that to a great depth the ground is almost exclusively clay. The soil near the harbour consists of soft mud to about 23 ft. below N. A. P., and below this there is a rather soft clay of even consistency, to about 36 ft. below N. A. P. and still deeper. The layer of clay is to a great depth very firm. Only thin layers of peat and sand are met with at about 30 ft. below N. A. P.

The impenetrability of clay to water has this advantage: that the excavation inside the wells can be made on dry soil. Should the well settle unevenly, the ground close to the highest side of the curb can be excavated deeper, and the well is again brought into its proper position.

Compared with pneumatic foundations, which under the existing conditions would have been equally suitable, cylindrical foundations have the following advantages:

The great quantity of iron, which has to be left behind, makes pneumatic foundations considerably more expensive.

The supervision of the construction of cylindrical foundations is much easier, as everything is done in the open air.

Pneumatic foundations, however, give more certainty that the desired results will actually be obtained, and, contrary to cylindrical foundations, an irregular formation of the soil, or a hard object does not cause serious difficulties. They have the further advantage that the ground surrounding the works remains undisturbed, while with circular foundations a shifting of the ground surrounding the cylinder cannot be avoided.

The portion of the quay wall at Delfzyl, which is built on cylinders, is 750 ft. long. It rests on 23 cylinders, each 31 ft. 2 in. long and 23 ft. wide, which are sunk 1 ft. 8 in. apart. The plan of the 23 cylinders is shown in Fig. 2 and the method of construction in Fig. 3.

The method of construction was as follows:

On the sand with which the site was filled to above low-water mark an iron curb or shoe was placed.

This shoe is 3 ft. 4 in. wide and ends at the bottom in a per-

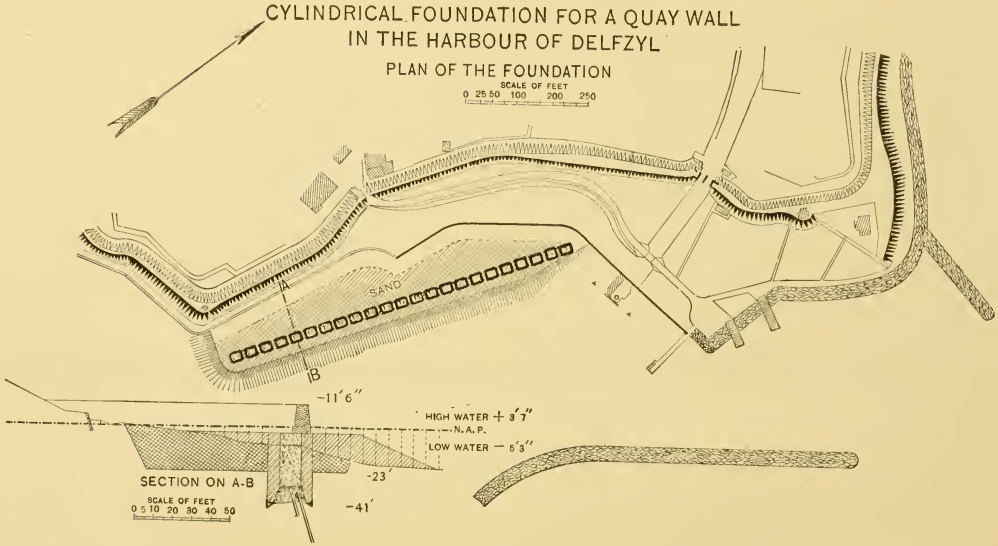

CYLINDRICAL FOUNDATION FOR A QUAY WALL
IN THE HARBOUR OF DELFZYL
PLAN OF THE FOUNDATION
SCALE OF FEET
0 25 50 100 200 250
SAND
A
B
-11′6″
HIGH WATER + 3′7″
N.A.P.
LOW WATER − 5′3″
SECTION ON A-B
SCALE OF FEET
0 5 10 20 30 40 50
-23′
-41′

FIG. 2.

pendicular plate, which cuts the ground like a knife. A section of the shoe has the shape of a right triangle which rests on one of its sharp angles, while one of the right sides is perpendicular to the horizontal plane. The two under sides are closed, while the upper side is open.

As soon as the shoe was put together on the sand filling, the inside was filled with concrete.

The brickwork on the shoe was begun at low water, and consisted of hard bricks of about $8\frac{5}{8} \times 4\frac{3}{8} \times 2\frac{3}{8}$ in., laid in cement, and costing about 23 cents per cu. ft. In this brickwork rails for anchoring were fixed, and it was built up to a height of 13 ft. As soon as it had settled sufficiently to form a compact mass, the excavation in the inside of the cylinder was begun, and in this way the cylinder gradually lowered. At the same time new layers of brickwork were laid in such a way that the top layer was always above high water.

The brickwork, which, at the upper edge of the shoe, is 3 ft. 4 in. thick, increases from there on in thickness, and is 6 ft. 2 in. thick at a height of 10 ft. The brickwork has to be very heavy in order to force the shoe into the ground, and when it is completed the weight of the cylinder is about 1 000 tons.

The average rate of sinking of the cylinders in the sand was 1 ft. 8 in. per day. This, however, decreased to 1 ft. 2 in. per day on reaching the clay, and to 8 in. in the very firm clay, more than 36 ft. below N. A. P.

As a rule, five workmen were excavating in one cylinder in dry ground.

Fig. 3 shows the method of excavation.

If a cylinder became filled with water it could be pumped out rather easily when the cylinder reached the clay. The influx of water was slight, so that it was only necessary to pump for a few hours daily.

As the upper edge of the cylinder had to be sunk to a depth of 3 ft. 5 in. below N. A. P., a temporary dam had to be placed around the cylinder during the last stage of the sinking. This temporary dam was constructed of iron caissons, which were hermetically fastened to the brickwork. The total height of a caisson was 12 ft 4 in., so that when the brickwork had been sunk to 3 ft. 5 in.

CYLINDRICAL FOUNDATION FOR A QUAY WALL IN THE HARBOUR OF DELFZYL

METHOD OF CONSTRUCTION

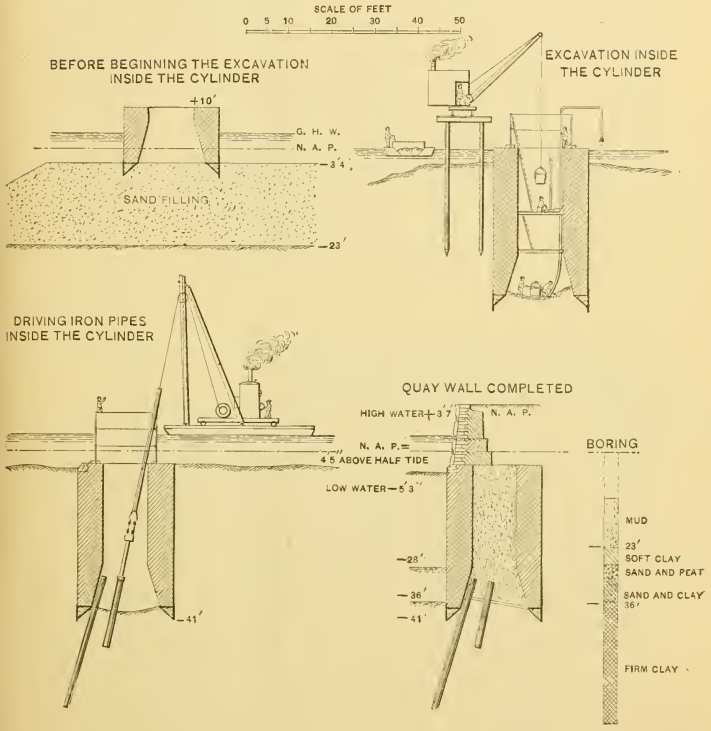


FIG. 3.

below N. A. P., the caisson projected to 5 ft. 4 in. above ordinary high tide, hence there was no danger of the cylinder's being inundated, except at unusually high water. The various parts of the caisson were bolted together with screws, so that they could easily be taken apart and used for another cylinder.

As soon as the shoe had reached a depth of about 40 ft. 6 in. below N. A. P., the excavation was stopped and iron pipes were driven into the ground. The reason for this was that the clay under the cylinder was not considered firm enough to carry the entire quay wall, with the load on top of it. There was also danger that the wall, under the pressure of the ground, might be pushed forward, if the foundation-wells filled with concrete were placed on the clay stratum without any further precautions.

Calculations show that, when the quay is in use, at the front of the foundation-well a pressure of at most 78 lb. per sq. in. will be exercised on the ground. As the clay cannot bear this pressure a portion of it must be borne by the iron pipes.

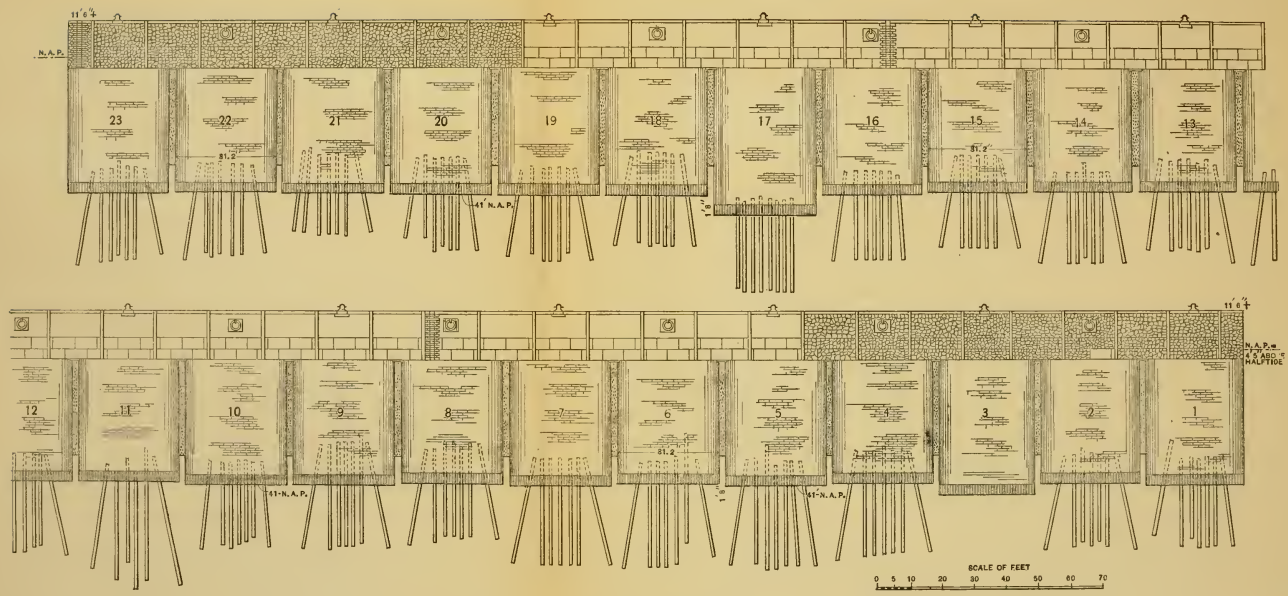
Inside of each cylinder two rows of pipes were driven, one behind the other, the first row consisting of 7 pipes from 28 ft. 9 in. to 33 ft. long, the second row of 6 pipes from 12 ft. 4 in. to 16 ft. 5 in. long. The iron was from $\frac{5}{16}$ to $\frac{7}{16}$ in. thick, and the diameter of the pipes 16 in.

When a cylinder had been sunk to the required depth and pumped quite dry, two wooden guides with a heavy pile-driver weighing 2 000 lb. were placed in the cylinder. With this the iron pipes were driven in. The pile-driver was lifted up by a locomobile placed outside the cylinder, so that the engineer had to be informed by means of signals when he could start the engine.

The ramming was carried out in the usual way, with this difference, that it was not on the surface, but 38 ft. below N. A. P., or nearly 43 ft. below ordinary high-water mark. During the ramming the cylinder settled only a little. The vibration in the clay stratum, caused by the driving, did not cause much water to leak through, as might be supposed.

When a pipe was driven to a depth of 20 ft., the average rate of sinking obtained per stroke with a fall of 8 ft. was $\frac{1}{8}$ in. At a greater depth this decreased to $\frac{1}{16}$ in. per stroke. At this rate the pipe had a calculated resistance of 200 tons.

CYLINDRICAL FOUNDATION FOR A QUAY WALL IN THE HARBOUR OF DELFZYL



THE QUAY WALL

The 13 pipes which were driven in each cylinder (except in Cylinder No. 3) strengthened the subsoil considerably. They also afforded more security against the wall being pressed forward, although this could also have been obtained by sinking the cylinders deeper into the ground.

If these pipes are not protected from rust they cannot be depended upon to retain the same resistance permanently. They were, therefore, after being driven in, filled up with concrete strengthened with iron. Whenever the original iron pipe disappears by rusting, an iron-concrete pile will remain.

The lower end of the pipe has not been bored out and filled with concrete, so as not to remove the very firmly compressed clay, because this affords a good foundation for the concrete filling.

After the iron pipes were driven in, bored out and filled up with concrete, the foundation of the cylinder was levelled and the whole filled with concrete. The concrete was applied on dry ground.

It might be observed that the cylinders cannot be sunk in regular order, but that either the odd or even cylinders must first be made. If this were not done the condition of the ground on all sides of the cylinder would not be equal, which would cause an oblique settling. Therefore Cylinders Nos. 3, 5, 7, 9, 11, etc., were sunk, while Cylinders Nos. 4, 6, 8, 10, etc., were constructed afterward.

The spaces between the cylinders were filled with concrete to a depth of 33 ft. below N. A. P., and to a width of 13 ft.

In order to have sufficient space between the cylinders in which to work, a groove was made in the cylinders, so that the space between the cylinders, which otherwise is 1 ft. 8 in., over a distance of 13 ft., was increased to 3 ft. 10 in.

When the earth between the cylinders was removed, it was found to consist principally of sand coming from the sand filling. When a cylinder has sunk through this bed of sand and enters the clay, a layer of sand around the cylinder is carried down with it and sinks through the clay together with the cylinder.

The earth between two cylinders was easily sucked away after the opening on both sides had been shut off by a couple of piles. The opening between two cylinders was thereafter filled with concrete.

During the sinking of the cylinders a few accidents happened. A couple of cylinders settled unevenly, while, in two, cracks appeared in the brickwork at the time of sinking. Although the reparation caused many difficulties, it was possible to sink all the cylinders to the required depth.

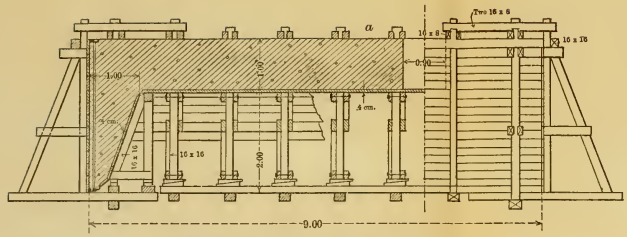
After the completion of the cylinders the quay wall was built on top. This consisted of concrete blocks, on top of which a layer of concrete was placed, with a covering of columnar basalt.

Plate IV shows the entire quay wall. The cylinders with their iron piles, and above these the continuous quay wall made of concrete blocks are shown.

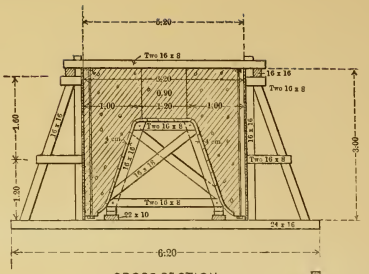
The cost of construction of the entire quay wall without dredging and sand filling behind the wall was $900 per yd.

The average cost of one cylinder, 31 ft. 2 in. long, 23 ft. wide, and sunk 41 ft. below N. A. P. was $5 840.

HOLLOW FRAMING FOR A CONCRETE CAISSON.

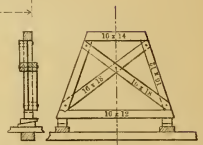


LONGITUDINAL SECTION AND ELEVATION

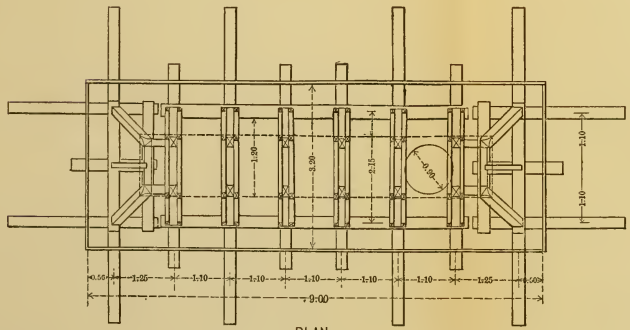


CROSS-SECTION

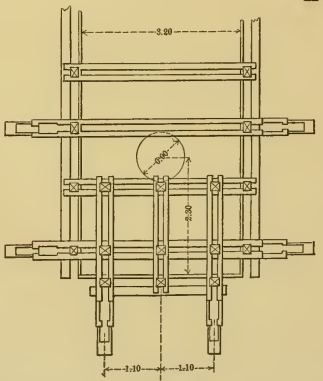
VARIATION FOR POINT *a*



VARIATION FOR INTERIOR TRESTLES



PLAN



TOP VIEW

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON
DEEP FOUNDATIONS.

By Messrs. O. E. Mogensen, K. E. Hilgard and W. F. Druyvesteyn.

Mr. Mogensen.

O. E. Mogensen, M. Am. Soc. C. E., St. Louis, Mo.—The design adopted by the author in the construction of foundations for a quay wall in the Harbor of Delfzyl in Holland appears to be well adapted to the conditions with which he had to deal, although at a glance it would seem cumbersome and expensive to fill up the site with sand nearly 20 ft. deep, and then, upon the completion of the wall, remove more than half of it by dredging.

It would be interesting to know how long it took to construct the quay wall. It has occurred to the speaker that the mortar used in the brick shell might be partly washed out or become weakened during rapid sinking, due partly to the wave action in the harbor, and partly to the water pressure after the cylinders have reached the bottom and the pumping has been started, unless, of course, ample time is allowed for the proper setting of mortar, or unless the brick ring is protected by a steel shell.

The author gives the cost of the entire quay wall, without dredging and sand filling, as $900 per yd. The wall is 750 ft. long, making the total cost, $225 000, or $9 800 for each cylinder, including the cost of driving the steel-concrete piling and the cost of the quay wall proper on top of the cylinders. For comparison with prices prevailing in the United States, the speaker has estimated, as nearly as available data will permit, that this cost averages $9 per cu. yd., which includes the foundation piling and all work excepting the dredging and the sand filling behind the wall. In making comparison, due allowance must be made between money values in Europe and the United States.

Mr. Mogensen. It is to be regretted that American engineers have not found occasion to contribute to the subject of "Deep Foundations" in the same manner as the other subjects have been treated, that is, by giving a general *resumé* of the advance during the last decade. It is not that this branch of engineering has been at a standstill.

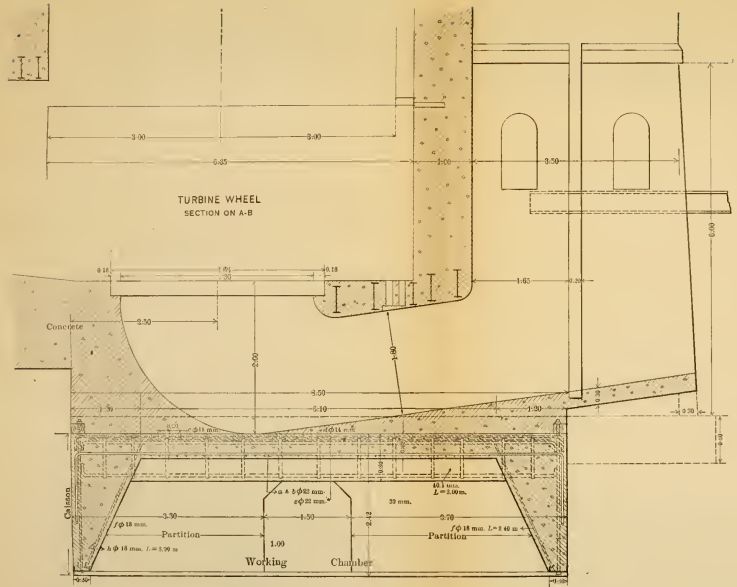
The use of steel sheet piling for cofferdam work is an advance in certain kinds of foundation work, inasmuch as it has been possible to use sheet piling of steel shapes, 50 ft. or more in length in lieu of the usual 25 or 30-ft. maximum length in timber, thereby avoiding more expensive and cumbersome methods. This steel sheet piling is particularly useful for the construction of continuous walls built in sections, and where it may be pulled and redriven in the consecutive sections.

Another feature in the line of foundation work is the use of concrete or reinforced concrete piles, driven by pile-drivers, in lieu of timber piles, especially in places where timber piling would suffice, but where it is not applicable on account of exposure to alternate moisture or dryness, or along the coast where the *teredo* makes the use of timber impractical.

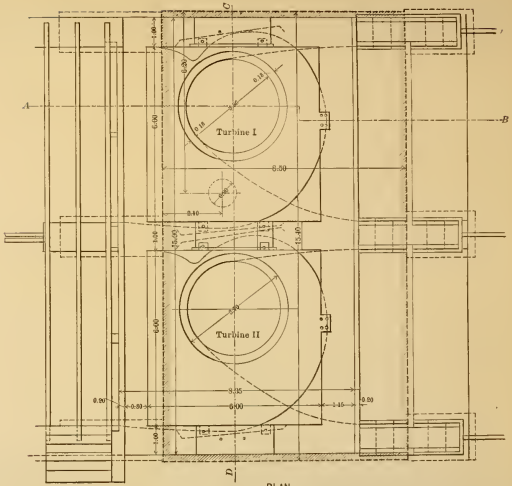
In the line of pneumatic foundations, especially for bridges, the timber caisson is still generally used, and, on account of the difficulty in securing steel shapes and plates, during recent years, in less than 8 to 12 months' time, the use of steel has been avoided as much as possible.

The speaker understands that caissons built entirely of concrete and reinforced concrete have been used in Europe in pneumatic foundations, and it would be interesting to hear of some examples thereof from some foreign engineers.

Mr. Hilgard. K. E. Hilgard, M. Am. Soc. C. E., Zurich, Switzerland.—It has been stated that it might be of interest to American engineers to know just what has been done in the way of utilizing concrete and reinforced concrete for pneumatic caissons in Switzerland, or other countries abroad. The speaker does not know whether this subject belongs in a discussion on deep foundations; probably in Europe there is a slightly different understanding as to that subject, all pneumatic foundations there usually being classified with deep foundations. In quite a number of cases of foundations, which have been brought to the speaker's attention, for structures which were not very large, but where the pneumatic process was resorted to, concrete was used exclusively to build the working chambers. He can refer to power plants which were built on the River Aare in Switzerland for which concrete was also used in the caissons, and to quite a number of piers and abutments of bridges crossing the various rivers in Switzerland. A very large number of pneumatic caissons, built of concrete and of concrete only, without any

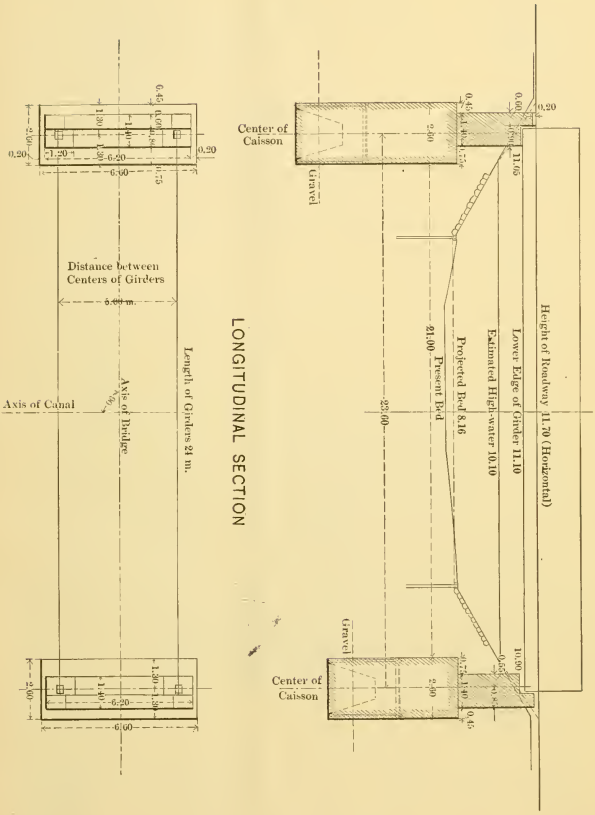


FOUNDATION OF TURBINE CHAMBERS
WITH REINFORCED CONCRETE CAISSON.



PLAN

Mr. Hilgard.



STREET BRIDGE AT BALGACH-SCHMITTER.

LONGITUDINAL SECTION

PLAN

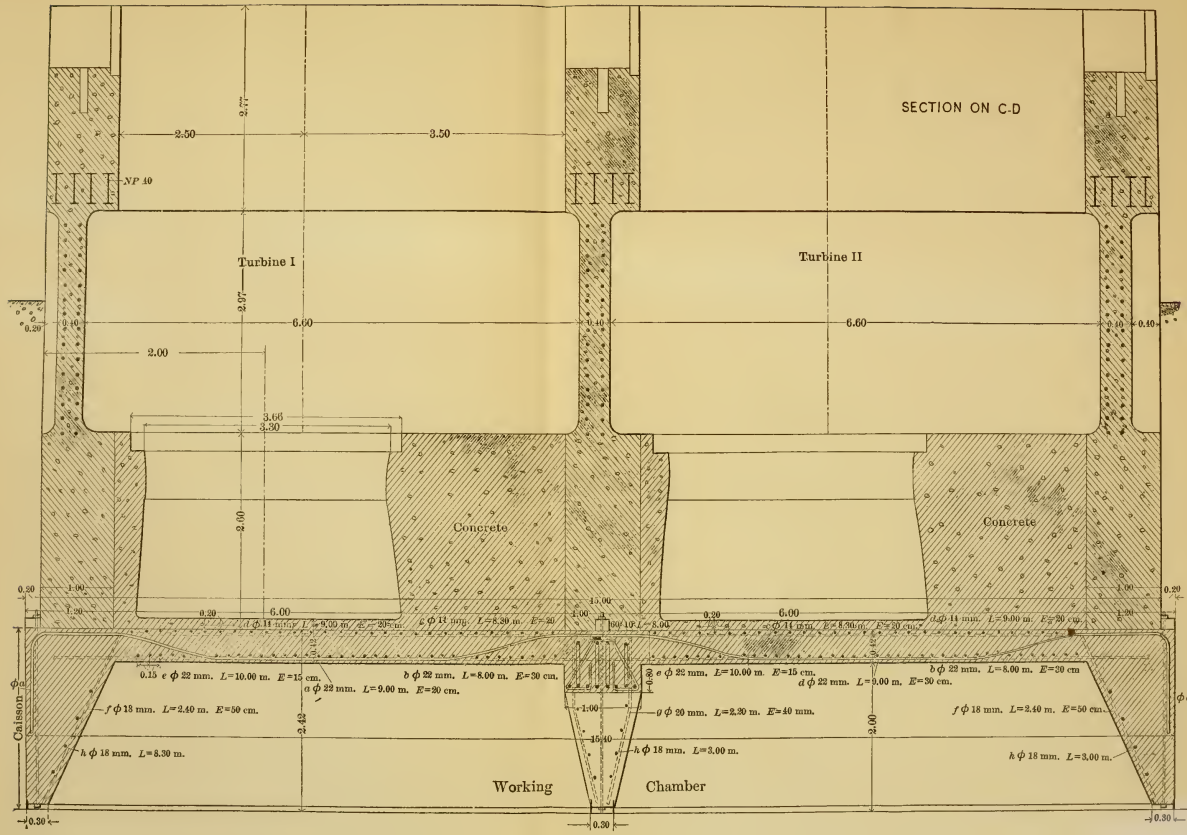
FIG. 1.

Mr. Hilgard. steel reinforcement, were used on the tributary work of the International Regulation of the Rhine in the Canton of St. Gallen.

Within the last few years, a great deal of work has been done for the regulation of the Rhine where it forms the boundary between Austria and Switzerland. Owing to this, the regulation of the tributary water-courses had to be anticipated; they had to be intercepted and carried in a separate channel which empties, near the mouth of the Rhine, into Lake Constance. A great many bridges had to be built across this intercepting "Binen-Canal," and all the piers and abutments of those bridges were founded on pneumatic caissons built of concrete. In Switzerland, these caissons are generally simply called concrete blocks (see Figs. 4 and 5). In cases where the foundations can be started on comparatively dry ground, a mould is built in place, and the concrete is filled into this mould and tamped. The shaft and the air locks are then set and the sinking commences. For the arrangement of the timber mould and staging, see Plate V.

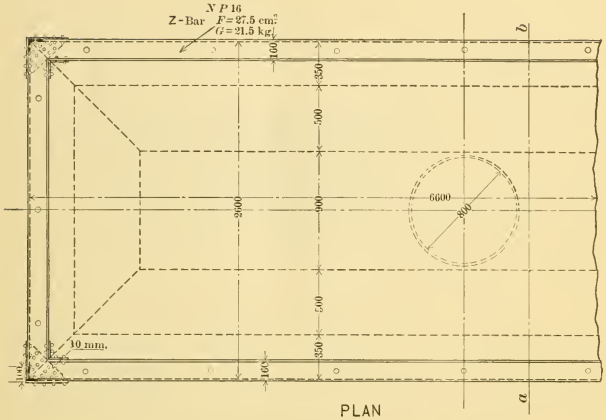
In other cases where there may be several feet of water (the speaker has seen cases in which there was as much as 6 ft. of running water), a temporary fill is made first, and in order not to extend the slopes of this island too far, sheet piling is resorted to, or the fill is confined by a row of piles with an interlacing of brushwork; thus, the current of the water cannot damage the fill. The moulding and staging for the concrete caisson is thus built up, and the sinking is started from the top of this fill above the water-line. Such concrete blocks are built up to 34 ft. in length by about 15 ft. in width. The working chamber of course has always a clear height of about 2 m., which is equivalent to about 6 ft. and some inches. The thickness of the roof depends upon the width of the caisson; usually it is about 1 m., which is equivalent to about 3 ft. 4 in. If the width of the caisson is more, of course the roof has to be correspondingly increased in thickness. The iron or steel in these small concrete caissons is used simply for the armature. In the first place, the cutting edge is usually formed of a plate with an angle riveted to it, or else a channel bar is used. If an eye-bar is used, one of the flanges is cut off so that the other flange forms the cutting edge; the cutting edge is anchored to the concrete with anchor rods. The washers under the anchor rods on top of the roof are not usually single washers; they are either channel bars, angles, or old railroad rails. Thus, one channel bar forms a washer common to all the anchor rods on one side of the caisson. An iron armature is similarly formed to protect the vertical edges of the block unless these are rounded off. The speaker has even seen such concrete caissons where, instead of channel bars or angles for washers of the anchor rods, simply embedded timbers were used, and they

PLATE VII. VOL. LIV. PART E.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
HILGARD ON
DEEP FOUNDATIONS.

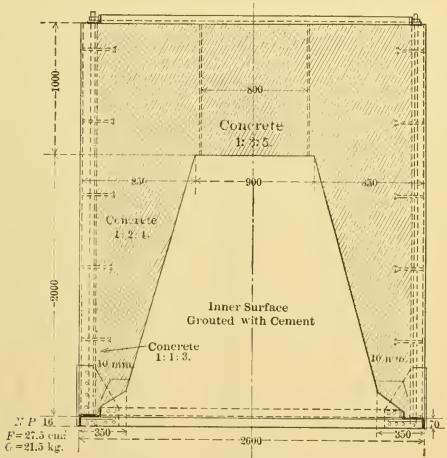


Mr. Hilgard.

CONCRETE CAISSON
FOR THE STREET BRIDGE AT
BALGACH-SCHMITTER.



PLAN



CROSS-SECTION ON *a-b*

FIG. 5.

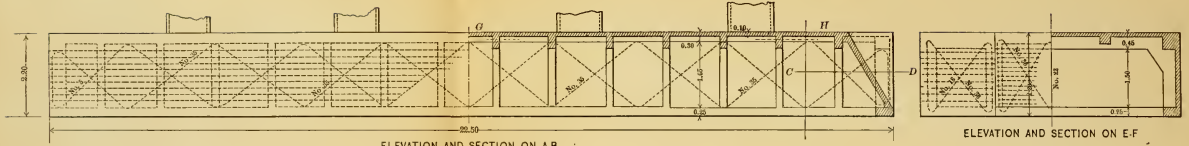
Mr. Hilgard. gave very good satisfaction. He has also seen old steel rails embedded in the body of the roof, as a reinforcement, and, of course, they impart considerable additional strength. In some cases, the roofs have to be made very thin, and in these cases the regular system of reinforced concrete is applied (see Plates VI and VII). The system used in Switzerland and for most of these reinforced concrete caissons is that best known in Europe as the "*système Hennebique.*"

The speaker has also seen concrete caissons where the side walls were reinforced as well as the roof, particularly where they had to be made rather thin; in the ordinary concrete caisson, the side walls are very thick. Ordinarily the side walls taper from roof to cutting edge, where they have a thickness of about 18 in., and from there the thickness increases toward the roof to a thickness equal to that of the roof or more. The lower ends of the shaft are anchored directly into the concrete of the roof. The shaft is usually the same as in steel or timber caissons, formed of sections of riveted pipe, or even of reinforced concrete pipe in some cases. The rest of the equipment of the caisson is the same as in the ordinary caisson. A very good example of a reinforced concrete caisson was used in building the new dock near Cadiz, Spain. The problem there was a very difficult one. The ordinary steel caisson proved far too expensive and too heavy, and, in order to decrease the weight and yet give a much larger base to the concrete caisson in the soft mud through which the caisson had to be sunk, a very wide cutting edge (it was really not a cutting edge, but rather a flat supporting base) was provided under the side walls of the concrete caisson (see Plates VIII, IX and X). The caissons which were used for the foundation of the dry dock in San Fernando, Spain, for the Arsenal of Carraca were all built in "*système Hennebique.*" Every portion of these caissons was reinforced with the usual arrangement of rods tied with straps. The speaker has been told that they were satisfactory, and have proved to be air-tight.

The other ordinary caissons, mentioned above, give very good satisfaction so far as being air-tight is concerned. It goes, of course, without saying that on the inside they are grouted with pure cement mortar. Concrete itself, in the bulk, as is well known, is not tight at all—neither against water pressure and still less so against air pressure, but the grouting with pure cement mortar, 1 in. in thickness, gives very good satisfaction in this regard.

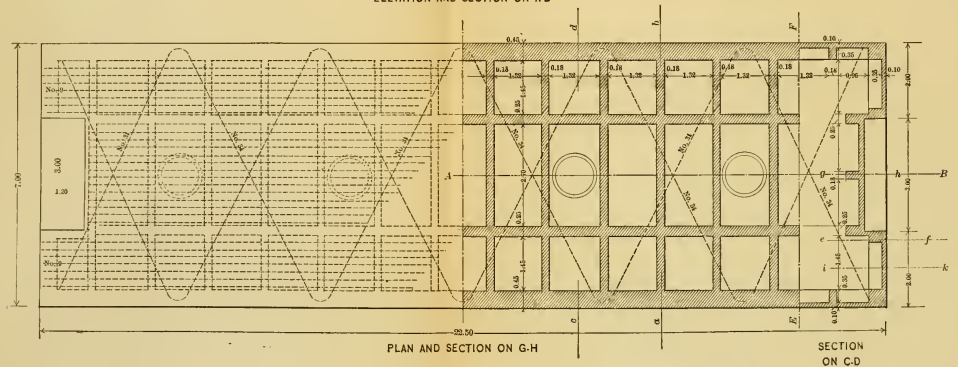
As to the size to which such concrete blocks are usually made, it must be borne in mind that one must guard against making them too long in proportion to their width. It was found that some of these concrete blocks that were made four or five times as long as their width were broken in two. The damage could be repaired by rein-

PNEUMATIC CAISSON OF REINFORCED CONCRETE, HENNEBIQUE SYSTEM, FOR THE ARSENAL OF CARRACA, SAN FERNANDO.



ELEVATION AND SECTION ON A-B

ELEVATION AND SECTION ON E-F



PLAN AND SECTION ON G-H

SECTION ON C-D

forcing them with tie-rods and iron braces after they were broken, but experience has shown that it is not wise to make them more than three times as long as they are wide. Mr. Hilgard.

Some of these blocks were sunk to a depth of 20 or 25 ft. below the ground, and as has been said, they are not generally used where one has to start in water, or where the water is deep. Some were sunk to a depth of 30 or 35 ft. and, so far as the speaker could learn, they gave very good satisfaction. They proved more economical than iron or steel caissons, inasmuch as the concrete block forms in itself a large portion of the body of the foundation.

The speaker might also mention some power-houses which were built for water-power development. In one, the entire power-house is built of several of these blocks where each block forms directly the foundations for one of the turbine chambers, and, while it was being sunk, the latter was gradually being built up on top of the roof. Plates VI and VII represent two turbine chambers, both built on one common caisson of about 52 by 24 ft., which had an exceedingly shallow roof and was well reinforced. To save time, the building of the turbine chambers was commenced before the sinking of the caisson was started. It was rather a difficult matter, because the concrete for the turbine chamber formed a very unequal load, and special provision had to be made, on account of the gradual shifting of the center of gravity, during the construction of the entire chamber, in order not to get the foundation of this power-house chamber into an inclined position by tilting.

The speaker has no doubt but that these caissons might be used for the limit of pneumatic foundation work, but, of course, he would never use them in ground where many large boulders are apt to be encountered; in homogeneous ground like sand or gravel they have given very good results. Neither would he ever attempt to use them where they would have to be sunk through any great depth of water to begin with, inasmuch as they cannot easily be floated, at least, no attempt has been made to float them with a blind bottom. No doubt it might be done, but it would be rather cumbersome and involve a great deal of expense, whereas, if one can start on a ground which, at some time of the year, is dry, or where one can, with a limited quantity of fill, produce a dry bottom to start with, the speaker would certainly advise using them. Blasting of boulders and cutting through old timbers and sunken logs were also successfully carried out in one case within his knowledge. The speaker has seen timber caissons used in the United States where, in Switzerland, we certainly would not have thought of using anything else but concrete blocks.

So far as the speaker's knowledge goes, the first time pneumatic caissons were built entirely of concrete was about twelve or fifteen

Mr. Hilgard. years ago. They are in reality nothing but the evolution of the original type of masonry caissons which really preceded some of the iron-work which was used in the first stages of the application of compressed air to foundation work. In Europe, in some countries, such as Germany, with some notable exceptions, Switzerland, Italy and France, pneumatic timber caissons are seldom used, but they might have been used, in some cases, to good advantage.

They have been used in Germany more during the last few years than ever before, and a very noted German handbook on civil engineering, treating of pneumatic foundations, which was published three or four years ago by an experienced authority on this subject, states "that in the United States timber caissons were used, for instance, for the St. Louis Bridge and also for the Brooklyn Bridge, but they never proved a success and have not been resorted to since." The speaker cannot imagine that the author of this handbook did not know any better. He must have taken it from a statement which the speaker once made within his reach of information to the effect that, in nearly 85% of all the pneumatic foundations made in the United States, timber caissons were resorted to and used with great success; that their application had been a great improvement over the old methods and their building and manner of construction had been greatly modernized and varied as is exemplified in some buildings in New York, where a different type of timber caisson is used from that which is used in bridge foundations.

The greatest depth, within the speaker's knowledge, to which concrete caissons have been sunk is about 35 ft. He does not doubt but that they could be sunk very much deeper, although he has no definite knowledge on this part of the subject. Where conditions for their use are favorable, some of the advantages of concrete caissons *versus* steel caissons are:

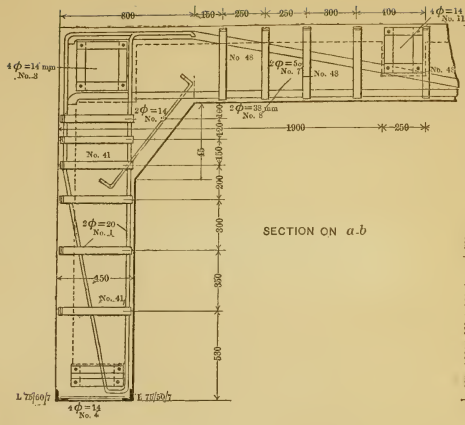
1.—It is easier to insure absolute adhesion of the concrete forming the caisson to that caisson or to the masonry which is being filled into the working chamber and to that masonry which is being built up over the roof.

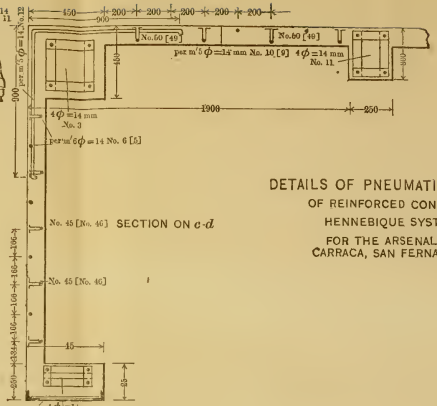
2.—The caisson block forms a vital part of the bulk of the foundation and not a mere shell, as in the case of riveted steel-plate caissons.

3.—The caisson is cheaper and in consideration of (2) the entire foundation is cheaper.

4.—The construction of the caisson is a simple matter and ordinarily can be started almost at once, the necessary material being always on hand.

5.—By using a concrete caisson, the process of sinking can be started and completed before, in most cases, a riveted steel caisson could be built and made ready for sinking.



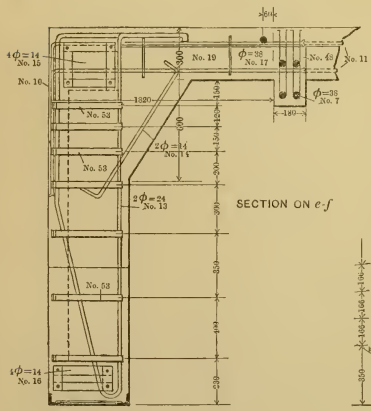


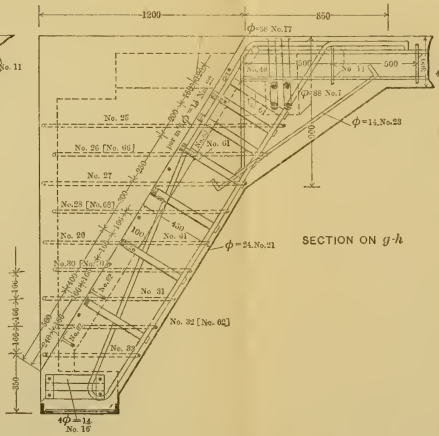
DETAILS OF PNEUMATIC CAISSON

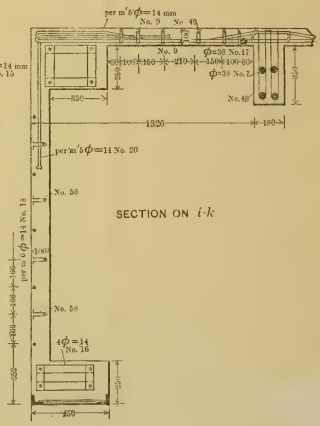
OF REINFORCED CONCRETE.

HENNEBIQUE SYSTEM.

FOR THE ARSENAL OF CARRACA, SAN FERNANDO.







W. F. Druyvesteyn, Esq., Flushing, The Netherlands.* (By letter.)—For the construction of foundations for a quay wall in the harbour of Delfzyl, the site was filled up with sand, nearly 20 ft. deep, and, upon the completion of the wall, the sand was removed by dredging. In judging the design, adopted for this construction, it must be remembered that sand can be obtained from the River Ems in the neighbourhood of the harbour, and the mud can be deposited in the river one mile distant, so that the work is not expensive. Mr. Druyvesteyn.

The cost of dredging and filling up the site was 28 cents (American currency) per cu. m. (1.3 cu. yd.). The cost of dredging, transporting and depositing the mud in the river was 8 cents (American currency) per cu. m. (1.3 cu. yd.).

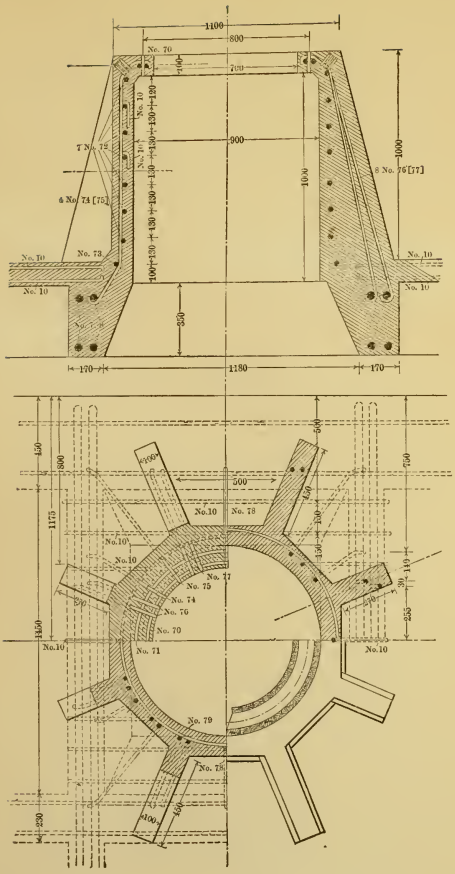
It was very important to construct a strong base of sand, upon which the foundation cylinders could be erected, because each cylinder is very heavy, and because the mud behind the quay, at all events, ought to be replaced by sand.

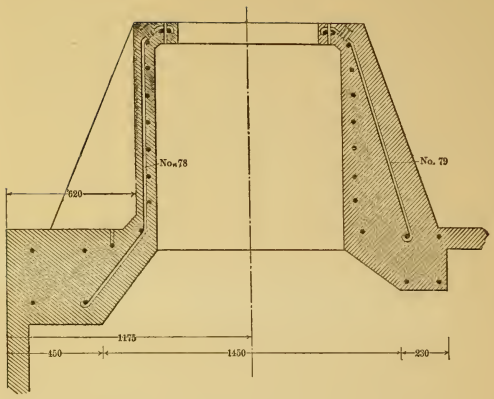
In building a cylinder and sinking it, one must take care that the masonry does not come in contact with the water, before it is five days old, so that the mortar can harden.

It has seldom happened that the mortar used in the brick has been washed out by the wave action in the harbour.

The sinking of the first cylinder began on April 18th, 1902, and the last or twenty-third cylinder was sunk to the required depth on November 21st, 1903, so that the work of sinking lasted about 1½ years. Although the work did not stop entirely in winter, only a very small part of it was done during the months of November, December, January and February.

* Engr., Corps of Waterstaat, Holland.





PNEUMATIC CAISSON OF REINFORCED CONCRETE,
(HENNEBIQUE SYSTEM.)
FOR THE ARSENAL OF CARRACA, SAN FERNANDO.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

SEWAGE DISPOSAL.

Congress Paper No. 64.

SEWAGE DISPOSAL IN AMERICA.

By George W. Fuller, M. Am. Soc. C. E., New York City, U. S. A.

Congress Paper No. 65.

SEWAGE DISPOSAL IN FRANCE.

By M. Bechmann, Ingénieur en Chef des Ponts et Chaussées, Chef du Service des Eaux et de l'Assainissement de Paris, Paris, France.

Discussion of the Subject by

J. L. Van Ornum, St. Louis, Mo., U. S. A.
M. N. Baker, New York City, U. S. A.
Dr. Samuel Rideal, London, England.
Dr. Gilbert Fowler, Manchester, England.
J. M. Coane, Melbourne, Victoria.

W. Thwaites, Melbourne, Victoria.
H. Ross Hooper, London, England.
Andrew Rosewater, Omaha, Nebr., U. S. A.
Allen Hazen, New York City, U. S. A.
H. N. Ogden, Ithaca, N. Y., U. S. A.
E. J. Hanley, St. Louis, Mo., U. S. A.
H. Birch Killon, Manchester, England.
Rudolph Hering, New York City, U. S. A.
Robert Spurr Weston, Boston, Mass., U. S. A.
M. O. Leighton, Washington, D. C., U. S. A.
John W. Alvord, Chicago, Ill., U. S. A.
F. A. Barbour, Boston, Mass., U. S. A.
George W. Fuller, New York City, U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 64.

SEWAGE DISPOSAL.

SEWAGE DISPOSAL IN AMERICA.

By George W. Fuller, M. Am. Soc. C. E.

The vast majority of American communities dispose of their sewage now, as was the case 10 years ago, by dilution or dispersion in relatively large volumes of water.

The urban population of the United States was estimated by the Census Bureau in 1900 at 28 411 698, or 37.3% of the total population. For this purpose the aggregate population of cities and towns of more than 4 000 population was taken, there being 1 049 of these. This limit in population has been used by quite a number of engineers as giving a fairly reasonable index to the population connected to sewers, on the basis that the population using sewers in towns smaller than this, and in isolated establishments, offsets in a general way the proportion of population unconnected with the sewerage systems of the larger towns and cities.

A rough classification, for purposes of illustration, of the princi-

pal methods utilized in this country for the disposal of sewage at the present time gives the following approximate results:

	Population.
Discharging raw sewage into the sea or into harbors or tidal estuaries along the seacoast	6 500 000
Discharging raw sewage into inland streams or lakes (by difference)	20 400 000
Connected to systems where sewage purification works are employed	1 100 000
	28 000 000

Compared with corresponding figures from older countries abroad, it is seen that sewage disposal in this country by purification works of artificial construction is still in its infancy. This is not so much to be wondered at when consideration is given to the large area, over which the population is quite scattered, and when it is realized that 10 years ago there were only about twenty such plants worthy of the name, and that hardly one of the purification plants now in service is more than 15 years old.

In reviewing recent progress and current practice in sewage disposal, the subject will be taken up as a matter of convenience under three headings, corresponding to the methods referred to above, namely, disposal by dilution in salt water, in fresh water and by purification works.

Sewage Disposal by Dilution in Salt Water.

Substantial advances have been made in the past 10 years in the adoption of this method of sewage disposal by cities situated sufficiently near the coast to make its cost come within their means. The most important works developed in accordance with this plan are perhaps those of the Metropolitan Sewerage District in and around Boston, Mass. Here the works have not only been improved and enlarged for the disposal of the sewage of Boston itself into the harbor, but there have also been added important trunk sewers extending up the Charles, Mystic and Neponset Valleys, and receiving the sewage of adjoining cities within some 15 miles or so of the harbor. This has caused the

abandonment of the chemical precipitation plant known as the Mystic Valley works, and has doubtless averted the necessity of building purification works at a number of places within the limits of the present metropolitan district.

The general effect of disposal of sewage into Boston Harbor was investigated a few years ago for the Metropolitan Sewerage Board by Mr. H. W. Clark, and more recently at this and other points along the Massachusetts coast for the Massachusetts State Board of Health by the Chief Engineer, X. H. Goodnough, M. Am. Soc. C. E. From these investigations, and other experiences, it may be said that this method of disposal gives reasonably satisfactory results where currents and depths of water are favorable, provided the sewage is screened to remove the larger suspended matters, and, further, so discharged that incoming tides will not carry the sewage to the mainland. Under these circumstances no objectionable deposits occur, and noticeable odors are confined to the immediate vicinity of the outlet. Where well-screened sewage is discharged in moderate quantities through each outlet into deep sea water where good currents exist, the only way in which its presence is indicated is by a very thin film of oily matter upon the surface, and this is hardly noticeable when there is much wind.

On the other hand, there are many places along the Atlantic coast where objectionable results have followed this method of sewage disposal, due to the faulty location and construction of the sewer outlets. Usually these cases are where the sewage is so discharged that offensive deposits are exposed on flats that are uncovered on the ebb tide, and where the dilution is inadequate. Experiences of the past few years clearly show that in the future much more care must be exercised than in the past in this regard. In some cases objectionable conditions may be remedied by extending the outfalls into deep water where good currents exist, but in the instance of some seaport towns it appears to be only a question of time before sewage purification works are adopted.

The question of the infection of oyster beds by sewage is one which has within the past 10 years pressed itself upon the attention of the engineer in some cases. The evidence concerning it is not defined as clearly as is desirable, although much valuable work has been done at several places. It is hardly worth while to do more

in discussion of this question in this paper than to point out its significance and to state that it is a sufficiently serious matter in some localities to be very carefully considered by engineers.

In many cases where deep-sea disposal has been used for cities having combined sewers, the question of storm overflows into relatively small bodies of water has come up for serious consideration. Unquestionably the tendency now is to eliminate them to a much greater degree than was considered necessary a few years ago. This feature was carefully considered for the lower Charles River opposite the City of Boston, in connection with a dam to keep the mud flats from uncovering and to facilitate the establishment of a water park. Marginal conduits will remove this pollution. Among many interesting studies made upon the subject under the direction of J. R. Freeman, M. Am. Soc. C. E., Chief Engineer of the late commission appointed to consider its practicability, was one showing that sewage putrefies more quickly in salt water than in fresh water, other things being equal.

Notwithstanding the fact that in many cases much discretion and judgment are required in carrying out this method of sewage disposal, it seems to be looked upon with increased favor by engineers, where its cost approximates that of purification works. This is evidenced by recent reports recommending that the sewage of the lower Passaic Valley in New Jersey be carried in a trunk sewer (over 20 miles long) into the Upper New York Bay, and the probability that the sewage disposal works at Summit, N. J., are sooner or later to be abandoned and the city sewerage system connected to the trunk sewer extending through the valleys of the Rahway and Elizabeth Rivers and discharging into Staten Island Sound. This method is also being seriously considered at a number of other places, among which may be mentioned the valley of the Bronx River near the upper limits of the City of New York, where it has been suggested that the Cities of White Plains and Mt. Vernon join with other communities in constructing a trunk sewer leading to the Hudson River or Long Island Sound.

Sewage Disposal by Dilution in Inland Streams.

This method of disposal has been and will continue to be the prevailing one in this country for inland communities so situated

that natural or legal conditions do not compel them to go to the expense of building and operating purification works.

As to the conditions of the probable occurrence of nuisances in inland streams, caused by sewage pollution, there has not been much change in prevailing views of engineers during the past 10 years. Over 17 years ago, Rudolph Hering, M. Am. Soc. C. E., showed that in a general way seriously objectionable odors would not ordinarily occur when the sewage of a community is discharged under favorable conditions into large streams, the minimum flow of which provides a dilution of about 2½ to 4 cu. ft. per sec. per 1 000 population connected to the sewers. This was based upon the assumption that suspended matters are largely removed by sedimentation, either before or shortly after entering the stream. Manufacturing wastes, sedimentation in mill-ponds, accumulations of sediment, etc., affect this question, and no very sharply defined line can be drawn to specify the precise minimum degree of required dilution in streams. Recent investigations, made upon small Massachusetts streams by Mr. Goodnough, have shown that gross pollution does not result where the minimum dilution is as much as 6 cu. ft. per sec., but that such has occurred in all observed cases where it was less than 3.5 cu. ft. per sec. per 1 000 population. In most of these small streams, however, manufacturing wastes play a very important part.

Ten years ago views were not at all crystallized in this country among engineers as to the practical significance of those natural agencies which effect the so-called self-purification of streams. At present much more is known of this subject, and it is realized that for the large watercourses of this country, particularly the Mississippi River and its principal branches, self-purification of streams from the standpoint of the elimination of gross pollution is an important feature. Much light upon this subject has been obtained in an incidental way from the extensive investigations made in connection with water-purification projects at Pittsburg, Cincinnati, Louisville and New Orleans. It is a fact of much interest that the Mississippi River at New Orleans shows comparatively little trace of sewage pollution, although it receives the sewage of an urban population of about 9 000 000 persons. A fact of much bearing upon this result is that very little pollution reaches this

very large stream during the last 600 miles of its flow above New Orleans, as the drainage of the "delta" country is away from, and not into, the river. The mean and minimum stream flows are about 700 000 and 200 000 cu. ft. per sec., respectively.

With regard to a very important aspect of sewage disposal by dilution, namely, the likelihood of infection from typhoid fever and other water-borne diseases resulting from drinking the water of a stream which is sewage-polluted at a relatively distant point, views are not clearly crystallized. Voluminous evidence upon this subject has been introduced in connection with the pending litigation between the State of Missouri and the Sanitary District of Chicago relative to the infection of the St. Louis water supply by Chicago sewage discharged through the drainage canal (operated since January, 1900) into the Illinois River, which enters the Mississippi River some 30 miles above St. Louis. The distance from Chicago to St. Louis is, roughly, 350 miles, and the period of transit of sewage for this distance averages about 2½ weeks, becoming less than 10 days at times of flood flow. Pending further crystallization of this general evidence, and the decision of the U. S. Supreme Court in this particular case, it seems futile here to refer further to this subject, of which much will be heard in the future.

Undoubtedly engineers should recognize clearly the distinction between disposal projects by dilution where the prevention of gross nuisances alone is sought and where infection of waters used for drinking is a factor. This is true regardless of the question of filtration of water supplies. In general the legal aspect of water pollution is rapidly becoming an important matter for engineers to consider. Present evidence upon that subject is well outlined by Dr. John L. Leal in the *Proceedings* of the American Public Health Association for 1901.

Review of Progress in Sewage Purification Works During the Past Ten Years, with *Résumé* of Current Practice.

There are about 90 purification works now in operation in this country in towns and cities of over 3 000 population. About 65 of them have been built within the past 10 years. In 1900 there were 1 524 cities and towns in the United States having a population of

over 3 000, and about 1 100 of them, according to the Municipal Year Book for 1902, had more or less complete sewerage systems.

In smaller towns and at isolated hotels, institutions and industrial establishments there are several hundreds more, some of which are of much interest.

Table 1 shows the available data regarding the capacity and kind of municipal works now in service, based with few exceptions upon the replies received from a circular letter recently sent to the city engineers of the respective communities. For this information acknowledgment is due these gentlemen, and particularly to Secretary Probst and Engineer Pratt, of the Ohio State Board of Health, for portions of their unpublished records of the Ohio plants. This list is considered to be a fair guide as to the present status of affairs, although many desired data are as yet uncertain or lacking, and it is hoped that they may later be furnished, so as to make this list as complete and correct as possible for future reference.

There are two dozen or more places in the arid regions where sewage is used for irrigation purposes, but the local engineers hardly regard them as purification works. The data available now are very meagre, and with a few exceptions no effort is made to include them in Table 1. Through the efforts of Mr. M. O. Leighton, in charge of the Hydro-Economic Division of the U. S. Geological Survey, it is understood that data will later be available regarding the irrigation plants not here included. Acknowledgment is due this Bureau for data from several plants in the South and West which are included in this tabulation.

In Tables 2 and 3 are given classifications which, although of necessity quite arbitrary and only roughly approximate in some respects, it is believed indicate in general terms the progress that slowly but steadily has been made recently in this branch of engineering.

The most practicable sewage purification works for a given project depend to a very large degree upon local conditions, and accordingly current practice can with difficulty be summarized in brief terms except as regards a few truisms. It is perfectly safe, however, to state that intermittent sand filtration, or what is called by some "land treatment," gives the most efficient results, and that

it is the most economical for a majority of conditions in New England and sections of this country where ample areas of porous, sandy soil are available.

Sewage farming in the northern and eastern sections of this country has not been practiced with much success, and probably will not be, owing to the heavy rainfall during the harvesting season, although there is no reason why it cannot be adopted to a certain extent.

In the Far West, in what is known as the arid region, sewage irrigation can be used with success, and doubtless will be employed to an increasing degree in future years. The sanitary aspect of sewage irrigation thus far has usually been merely incidental to the process.

Experience shows that intermittent sand filters, while they are capable of giving substantially as good a degree of purification as indicated by the Lawrence data of a dozen years ago, cannot as a rule be operated advantageously at as high rates as was then thought to be the case. This is partly due to the relative increase in the cost of operation as the rates of filtration become higher, other things being equal, and partly to the difficulty in maintaining filters in satisfactory operation during severe winter weather, as regards clogging.

Where porous land is very expensive or available in limited areas, preparatory treatment for sewage, such as is effected by chemical precipitation, sedimentation, septic treatment or roughing filters, is an important matter; but there is no rule by which the question for any particular proposition can be settled without a careful consideration of the local conditions as regards cost.

Data regarding the cost of operating purification works are beginning to assume form which the engineer can use with moderate safety, although they are still meagre. This is especially true of plants where available records show the efficiency as well as the cost of operation.

Those processes, above referred to as preparatory treatments, namely, chemical precipitation, sedimentation, septic treatment and roughing filters, do not afford sufficient purification by themselves as a general proposition, although there are some exceptions to this rule, and they should ordinarily be followed by filtration.

TABLE 1.—List of Cities and Towns of over 3 000 Population, in the United States, where, According to Available Data, Sewage Purification Works are or have been in Operation during the Ten Years, 1894–1904, with Memoranda Indicating Roughly the Size and Character of Each Plant.

Date of installation of plant.	Place.	Population.		Average daily sewage flow, in gallons. (Estimated).	Tanks or basins.		Filtration.	
		Total in 1900.	Connected to sewers in 1904. (Estimated).		Kind.*	Total capacity, in gallons.	Kind.**	Total area, in acres.
1887.....	Coney Island, N. Y.....	?	Very variable	1 581 000	C. P.	21 780	None	0
"	" " "	?		680 000	C. P.	21 780	"	0
1888.....	East Orange, N. J.....	21 506	0	0	C. P.	225 000	Int. Irr.	14.7
1888.....	Mystic Valley, Mass.....	?	0	0	C. P.	?	None	0
1889.....	Framingham, "	11 302	7 500	652 000	R. B.	431 000	Int.	19.9
1890.....	Greeley, Colo.....	3 035	5 000	?	?	?	Irr.	25
1890.....	Worcester, Mass.....	118 421	122 000	15 550 000	C. P.	5 600 000	Int.	23
1891.....	Gardner, "	10 813	3 500	302 000	S. B.	10 500	Int.	2.5
1891.....	Marlborough, "	13 609	10 000	1 100 000	S. B.	16 000	Int.	11.2
1892.....	Hastings, Nebr.....	13 854	?	?	?	?	Irr.	15 ±
1892.....	Los Angeles, Cal.....	102 479	90 000	7 000 000	None	0	Irr.	2 000
1892.....	Summit, N. J.....	5 302	?	?	None	0	Int.	10
1892.....	Trinidad, Colo.....	5 345	?	?	S. B.	7 500	Irr.	?
1892.....	White Plains, N. Y.....	7 899	?	?	C. P.	30 000	None	0
1892.....	Sheepshead Bay, "	?	(Variable)	1 976 000	C. P.	18 400	None	0
1893.....	Canton, Ohio.....	30 667	11 000	2 000 000	C. P.	700 000	None	0
1893.....	Chatauqua, N. Y.....	?	(Variable)	?	C. P.	?	None	0
1893.....	Meriden, Conn.....	24 296	20 000	2 750 000	None	0	Int.	11
1893.....	North Brookfield, Mass.....	4 587	1 000	60 000	S. B.	6 000	Irr.	20.5
1893.....	Pasadena, Cal.....	9 117	10 000	600 000	None	0	Irr.	300
1893.....	Pawtucket, R. I.....	39 231	5 100	138 300	R. B.	65 800	Int.	3.4
1893.....	Westborough, Mass.....	5 400	3 000	282 000	S. B.	675	Int.	4
1894.....	Brockton, "	40 063	30 000	878 000	R. B.	619 000	Int.	21.5

* C. P. = Chemical precipitation; R. B. = Receiving basin; S. B. = Settling basin or grit chamber; Sep. = Septic tank.
** Irr. = Irrigation; Int. = Intermittent filters.

1900	Houston, Tex	44 633	15 000	1 000 000	None	0	Coke beds, Int.	12
1900	Independence, Mo	8 000	3 000	125 000	Sep.	262 000	Int.	0.3
1900	Manchester, Conn	10 601	6 000	1 500 000	None	0	Int.	12
1900	Mendota, Ill	3 736	?	?	?	?	Int. Irr.	2.5 8.0
1900	Shelby, Ohio	4 865	1 500	250 000	S. B.	1 250 000	Strainer	0.6
1900	Vineland, N. J	4 370	3 000	300 000	None	0	Int.	5
1901	Danville, Ky	4 285	?	?	Sep.	?	Sub.-surf. Irr.	? ?
1901	Depew, N. Y	3 379	3 000	100 000	Sep.	95 000	Contact	0.105
1901	Fond du Lac, Wis	15 110	8 000	1 000 000	Sep.	376 000	Contact	0.72
1901	Franklin, Mass	5 017	500	?	None	0	Int.	1.5
1901	Gardner, "	10 813	4 500	250 000	S. B.	168 000	Int. Coke strs.	2.25 0.5
1901	Kingston, N. Y	24 535	2 Wards.	?	Sep.	?	Contact	?
1901	Madison, Wis	19 164	15 000	1 000 000	Sep.	400 000	Double contin. int.	1
1901	Pittsfield, Mass	21 766	15 000	1 456 000	R. B.	1 500 000	Int.	22
1901	Princeton, Ill	4 023	?	?	Sep.	60 000	Int.	3.8
1901	San Luis Obispo, Cal	3 021	3 000	350 000	Sep.	52 000	Contact.	0.1
1901	Southbridge, Mass	10 025	2 200	350 000	Dosing	14 200	Int.	7.25
1902	Burlington, N. J	7 392	7 500	1 500 000	Sep.	120 000	Irr.	11
1902	Grinnell, Iowa	3 860	3 000	183 000	Sep.	225 000	None	0
1902	La Grange, Ill	3 969	4 000	200 000	Sep.	210 000	None	0
1902	Macomb, "	5 375	?	?	Sep.	?	?	?
1902	Mansfield, Ohio	17 640	8 500	1 000 000	Sep.	1 000 000	Contact	1.25
1902	Plainfield, N. J	15 369	9 000	800 000	Sep.	450 000	Double contact	1.79
1902	Providence, R. I	175 600	170 000	20 380 000	C. P.	11 100 000	None	0
1902	Red Bank, N. J	5 428	?	160 000	Sep.	100 000	None	0
1902	Santa Rosa, Cal	6 673	3 500	750 000	Sep.	310 000	Irr.	17
1902	Sherman, Tex	10 241	1 800	?	None.	0	Int.	8
1903	Monmouth, Ill	7 460	?	350 000	Sep.	400 000	None	0
1903	Muskogee, Ind. T	4 254	5 000	?	Sep.	50 000	?	0.5
1903	Pomona, Cal	5 625	4 000	200 000	Sep.	27 500	Irr.	15
1903	Saratoga Springs, N. Y	12 409	10 000 to 40 000	1 800 000	Sep.	1 000 000	Int.	21
1903	Visalia, Cal	3 085	4 000	240 000	S. B.	30 000	Irr.	70
1904***	Bedford, Ind	6 115	4 000	?	Sep.	85 000	None	0
1904	Durham, N. C	6 679	8 000	400 000	Sep.	250 000	Contact	?
1904	Iola, Kans	5 791	8 000	500 000	Sep.	167 800	None	0
1904	New Britain, Conn	28 202	24 000	3 000 000	None	0	Int.	31

* C. P. = Chemical precipitation; R. B. = Receiving basin; S. B. = Settling basin or grit chamber; Sep. = Septic tank.
** Irr. = Irrigation; Int. = Intermittent filters.
*** To June 1st.

TABLE 1—(*Continued*).

Date of installation of plant.	Place.	Population.		Average daily sewage flow, in gallons. (Estimated).	Tanks or basins.		Filtration.	
		Total in 1900.	Connected to sewers in 1904. (Estimated).		Kind.*	Total capacity, in gallons.	Kind.**	Total area, in acres.
1894.....	Oberlin, Ohio.....	4 082	3 000	200 000	S. B.	6 750	Irr. and Int.	1.25 and 3.5
1894.....	Princeton, N. J.....	3 899	?	?	?	?	Irr.	?
1894.....	Urbana, Ill.....	5 728	?	?	Sep.	?	None	0
1895.....	Bristol, Conn.....	6 268	4 000	?	?	?	Int. and Irr.	6 and 6
1895.....	Reading, Pa.....	78 961	?	2 000 000	?	?	Special	0.58
1896.....	Alliance, Ohio.....	8 974	4 000	500 000	C. P.	420 000	None	0
1896.....	Central Falls, R. I.....	18 167	3 931	40 000	S. B.	140 000	Int.	1.03
1896.....	Leicester, Mass.....	3 166	500	35 000	S. B.	2 400	Int. and Irr.	0.36 and ?
1896.....	Natick, "	9 488	4 000	566 000	R. B.	500 000	Int.	11.1
1896.....	New Rochelle, N. Y.....	14 720	5 000	500 000	C. P.	353 925	None	0
1896.....	Plainfield, N. J.....	15 369	0	0	None	0	Int.	16
1896.....	Salt Lake City, Utah.....	53 531	22 000	5 000 000	None	0	Irr.	150
1896.....	Santa Rosa, Cal.....	6 673	0	0	C. P.	72 000	Irr.	17
1897.....	Altoona, Pa.....	38 973	15 000	1 000 000	None	0	Irr.	59
1897.....	Champaign, Ill.....	9 098	5 000	350 000	Sep.	22 200	None	0
1897.....	Danbury, Conn.....	16 537	8 000	600 000	None	0	Irr. and Int.	5 and 5
1897.....	East New York, N. Y.....	66 086	60 000	7 680 000	C. P.	180 000	None	0
1897.....	Paris, Texas.....	9 358	2 500	15 000	S. B.	7 500	Int.	5.5
1897.....	Spencer, Mass.....	7 627	3 000	375 000	None	0	Int.	9.3
1898.....	Bakersfield, Cal.....	4 836	5 000	350 000	None	0	Irr.	100.0 +
1898.....	Kewanee, Ill.....	8 382	8 000	2 000 000	Sep.	450 000	None	0
1898.....	Ripon, Wis.....	3 818	1 200	?	?	?	Int.	1
1899.....	Aiken, S. C.....	3 414	3 000	160 000	Dosing	20 000	Int.	1
1899.....	Andover, Mass.....	6 813	3 600	125 000	S. B.	13 500	Int.	3.7
1899.....	Clinton, "	13 665	11 000	783 000	R. B.	670 000	Int.	23.6
1899.....	East Cleveland, Ohio.....	2 757	5 000	400 000	Sep.	170 000	Waring	0.45
1899.....	Glenville, "	5 588	?	400 000	C. P.	160 000	Int. and Strainers	1.0 and 0.19
1899.....	Marion, Iowa.....	4 102	2 000	200 000	Sep.	130 000	None	0
1899.....	Woonsocket, R. I.....	28 204	11 000	460 000	R. B.	500 000	Int.	2
1900.....	Concord, Mass.....	5 652	1 200	312 000	R. B.	242 000	Int.	3.3
1900.....	Fostoria, Ohio.....	7 730	3 500	400 000	R. B.	450 000	Int. and Irr.	6 and 14
1900.....	Holland, Mich.....	7 790	2 000	300 000	Sep.	60 000	None	0

TABLE 2.—SUMMARY SHOWING APPROXIMATELY THE NUMBER AND KIND OF PURIFICATION WORKS INSTALLED IN CITIES AND TOWNS OF OVER 3 000 POPULATION, BY YEARS, 1894-1904.

Year.	Total number.	Irrigation.		Chemical treatment (Powers Patent).	Chemical precipitation.	Intermittent Filters.					Coarse-Grained Filters.		Septic treatment alone.	Special designs.	Works now abandoned.
		Alone.	With septic treatment.			Alone.*	With settling basins.	With strainers.	With chemical precipitation.	With septic treatment.	Contact beds and septic treatment.	Continuous intermittent filters with septic treatment.			
1887–1893.....	22	6	0	4	4	7	0	0	1	0	0	0	0	0	2
1894.....	4	1	0	0	0	2	0	0	0	0	0	0	1	0	0
1895.....	2	0	0	0	0	1	0	0	0	0	0	0	0	1	0
1896.....	8	1	0	0	3	3	1	0	0	0	0	0	0	0	2
1897.....	6	1	0	1	0	3	0	0	0	0	0	0	1	0	0
1898.....	3	1	0	0	0	1	0	0	0	0	0	0	1	0	0
1899.....	7	0	0	0	0	4	0	0	1	0	1	0	1	0	0
1900.....	9	0	0	0	0	6	1	0	0	1	1	0	0	0	0
1901.....	11	0	0	0	0	1	1	1	0	2	4	1	0	0	0
1902.....	10	0	2	0	1	0	0	0	0	0	2	0	4	0	0
1903.....	5	1	1	0	0	0	0	0	0	1	0	0	2	0	0
1904.....	4	0	0	0	0	1	0	0	0	0	1	0	2	0	0
Totals.....	91	11	3	5	8	31	3	1	2	4	9	1	12	1	4

* In this column are included those plants where the basins used are either storage reservoirs or too small to be properly classified as other than grit chambers.

TABLE 3.—SUMMARY OF THE NUMBER OF DIFFERENT TYPES OF SEWAGE PURIFICATION PROCESSES IN 1904 IN TOWNS AND CITIES OF OVER 3 000 POPULATION IN THE UNITED STATES, REGARDLESS OF THE COMBINATIONS OF PROCESSES AS FOUND, AND WITH ROUGH ESTIMATES OF THE POPULATION CONNECTED TO EACH.

	Number of plants.	Population.
Irrigation	14	200 000
Intermittent sand filtration	41	250 000
Chemical precipitation	8	320 000
Chemical treatment (by Powers Patent)	5	125 000
Sedimentation (excluding grit chambers and receiving basins)	3	8 000
Strainers, or roughing filters	4	20 000
Coarse-grained filters at high rates	10	95 000
Septic treatment	29	160 000

It is hardly feasible to state now which of these preparatory treatments is best, as it depends much upon the quantity and quality of the sludge contained in the raw sewage. None of these treatments eliminates the bothersome and expensive question of sludge disposal. The septic tank gives much promise for small works treating domestic sewage, but in the case of very large works, receiving sewage containing much suspended mineral matter, the sludge question is a grave proposition.

The sludge question is an important and expensive matter in connection with all methods of sewage purification, whether intermittent sand filters, sedimentation, chemical precipitation, septic treatment or rapid filtration through coarse-grained materials. Other perhaps than at the very low rates used in sewage farming, the sludge bears directly upon the cost of operation and indirectly upon the size of plant and construction cost.

In the southern and central portions of this country, where the glacial drift formation and areas of porous land are absent, intermittent sand filtration is not ordinarily an available process, and it is necessary to consider in many places more recent methods, involving the use of coarse-grained filters operated at fairly high rates and preceded usually by some form of preparatory treatment.

In cases where the infection of watercourses with disease germs is not a factor, it seems reasonable for the present to secure a degree of purification which precludes putrescibility of the effluent and the resulting objectionable odors. Whether future experiences will justify the use of rapid filters, which produce somewhat turbid and unsightly effluents, without subsequent treatment of the effluent, is more or less an open question.

Contact beds and other coarse-grained filters of recent development are not as economical as at first supposed, and by some engineers are looked upon with less favor than their merits justify. It is not reasonable to throw them out of consideration because they require cleaning from time to time; if this were true, sand filters would be eliminated because they require harrowing and scraping.

Statement of Current Views and Experiences Regarding Sewage Purification Works.

In view of the difficulty of showing clearly in a brief *résumé* current practice in this field of engineering, on account of the wide

range in geological, climatic and other conditions in different sections of this country, and the meagreness of existing data of cost, it seems desirable in setting forth the present state of the art to supplement the foregoing summary with a brief statement of prevailing views and experiences upon some of the leading topics connected with this subject, as follows:

General features of sewage purification practice.
Broad irrigation.
Sub-surface irrigation.
Intermittent filtration.
Sedimentation.
Chemical precipitation.
Septic treatment.
Strainers, or roughing filters.
Strainers with enforced aeration.
Contact filters.
Continuous intermittent filters and sprinkling filters.
Automatic devices for the application of sewage.
Patents.

In the following pages use has been freely made of the records and data contained in various reports and papers upon the projects referred to, and especially the reports of Mr. H. W. Clark, for the past nine years in direct charge of the investigations of the Lawrence Experiment Station, of the Massachusetts State Board of Health, acknowledgment of which is made hereby. The important investigations at Lawrence have been conducted uninterruptedly since 1887, under the general direction of Mr. Hiram F. Mills, C. E., who presented some of the results of the earlier Lawrence work at the International Engineering Congress at Chicago in 1893.*

General Features of Sewage Purification Practice.

Objects Sought.—Two different objects have thus far been sought in the sewage purification works in this country. Quite a number of the older and more important plants in the neighborhood of Boston, Mass., were built with the view to purifying very thoroughly the sewage of small cities upon the drainage area of the Boston water supply, so that when the latter, containing a small

* *Transactions*, Am. Soc. C. E., Vol. XXX, p. 350.

percentage of well-purified sewage, was stored in large reservoirs for comparatively long periods it was considered to be unnecessary to filter it. This plan of removing the pollution entering the source of supply was largely a business proposition, based on the smaller cost of filtering the sewage of the Towns of Framingham, Marlboro, Westboro, Natick, etc., as compared with that for filtering the entire water supply of Boston. The City of Boston contributed materially to the cost of building several of these sewage purification plants. The other object sought is the ordinary one of preventing nuisances from decomposition and putrefaction in the watercourses into which the sewage is discharged, especially at times of low stream flow.

Standards of Purity.—As to standards of purity for sewage after purification, there has never been developed in this country anything in specific terms along this line which has received particular attention.

Separation of Storm Water.—The large degree of dilution of the sewage of American communities as compared with that abroad is well known, and adds somewhat to the comparative expense of purification works here, especially where it is necessary to pump the sewage. Where sewage purification works are built contemporaneously with or shortly after the collecting system, the separate system of sewers is used. Where purification works are adopted in cities already having sewers on the combined plan, this is naturally not feasible in all instances, although in many cases the separation of storm water is now carried out as rapidly, and as far as local funds and conditions will allow.

Reason for Restricting Water Waste.—The water consumption of American cities generally ranges from 50 to 300 U. S. gal. per inhabitant daily, and averages about 135 gal. Where sewage purification works are necessary, the extra expense due to these large quantities becomes an important reason for the reduction of needless water waste, and one which is perhaps not fully appreciated at present.

Treatment of Storm Flow.—At times of heavy rainfall it is the custom in many places, even where the collecting sewers nominally carry domestic sewage only, to divert a considerable portion, or all, of the storm flow and ground-water leakage, wherever possible or permissible, into adjoining streams. In fact, it is believed that there

are very few purification plants where, to a certain degree, this practice is not resorted to occasionally. Storm overflows, however, are not used as indiscriminately as formerly in connection with watercourses used for water supplies or flowing through parks, etc. No general rule obtains regarding the volume of storm flow, as compared with the dry weather flow of the sewer, which must be treated by purification works, before the raw sewage is partly or wholly discharged into the stream.

Trade Wastes.—Manufacturing wastes as a general proposition are disposed of in this country in the easiest and cheapest way for the manufacturers. In some instances at isolated plants steps have been taken to remedy the pollution so caused, but progress is slow except where remedial measures result from litigation. In some places these wastes increase the difficulty and expense of purifying city sewage to a marked degree.

Freshness of Sewage.—The freshness of sewage as it reaches the purification works is not in all cases such an essential feature as was considered to be the case by some engineers a few years ago. As sewage reaches the outfall, in many, if not most, cases in this country, it still contains dissolved oxygen (coming from the water supply), and the suspended matters are only partially disintegrated and separated into finer particles. In this condition sewage can undoubtedly be treated to best advantage by sedimentation, chemical precipitation, roughing filters or strainers. Upon flowing through an extended system of sewers (or remaining in tanks, etc.), sewage becomes "stale," that is, bacterial activity causes the oxygen to become exhausted and the suspended matter becomes more finely divided. In this condition sewage does not clog filters at the surface so rapidly as when fresh, and the organic matter is so changed that, other things being equal, it can apparently be purified to somewhat greater advantage than when fresh.

Composition of Sewage.—The wide differences in the composition of sewage from various American cities make it essential to keep this feature in mind in comparing the experiences in sewage purification at different places. It is of even greater significance in comparing American and European experiences and *vice versa.* In Table 4 are given data on the composition of the sewage of certain American cities, together with similar data from some of the larger English cities, as they have been compiled by the writer.

The differences in the amounts of the several constituents are not explained wholly by different degrees of dilution, as it is necessary to consider some of the characteristics (street washings, trade wastes, etc.) of the city from which the sewage comes. Trade wastes in particular affect the individuality of sewage, making it essential that this matter in each case receive attention independent of the domestic sewage and street washings. This phase of the subject can be best studied, for the purposes of the engineer, by the estimated amount of the several constituents of sewage expressed in grams per capita only, as given in Table 5. The quantities given in this table correspond to the same figures, according to different forms of expressing the results of the analyses, when the volume of sewage in U. S. gallons per capita daily is as follows:

Parts per 1 000 000	264.0 gal.
" " 100 000	26.4 "
Grains per U. S. gallon	15.4 "
" " Imperial gallon	18.5 "

In estimating the constituents of sewage, from the data in Table 5, corresponding to any dilution and in any one of the four methods of expressing the analyses, it is only necessary to divide by the number of gallons in the list last given and multiply by the number of U. S. gallons for the case in hand.

Sewage Sludge.—The question of suspended matter, that is, the sludge contained in the sewage, is by no means one upon which the evidence has taken its final form. While it is obviously an important item of cost in connection with chemical precipitation works, sedimentation and strainers, it is also a factor with septic tanks, contact beds and even with intermittent filters of porous sand when consideration is given to long periods of service. Unfortunately sludge data for American sewages (see the suspended matter in the foregoing tables) have not been studied as thoroughly as is desirable, but during the past few years they have been receiving in a much larger measure than formerly the attention which the subject deserves. A better appreciation of the quantity of dry suspended matter in crude sewage may be obtained by expressing it in tons (2 000 lb.) per 1 000 000 gal. and per 1 000 population per annum as given in Table 6. In a rough way a ton of wet sludge corresponds to about $1\frac{1}{3}$ cu. yd. as it lies on the bottom of a settling tank.

TABLE 4.—Average Analyses of Representative Sewage from Massachusetts and English Cities, with Estimated Corresponding Volume per Capita Daily.

Parts per Million.

Place.	Massachusetts Cities.				English Cities.					
	Framingham.	Gardner.	Marlboro.	Worcester.	Huddersfield.	Leeds.	Leicester.	London, North.	London, South.	Manchester.
Average daily flow of sewage per capita: U. S. gals.	73	100	113	150	108	60	60	48	60	72
Imp. "	63	83	95	125	90	50	50	40	50	61
liters	275	375	430	562	410	225	225	180	225	275
Oxygen consumed: 4 hr. at 80° fahr.	37*	20*	12*	47*	99	126	107	80	67	118
Oxygen consumed: 5 min. at 212° fahr.	62	34	20	78	165*	210*	180*	133*	112*	197*
Nitrogen as: free ammonia	21.5	15.8	7.7	11.2	10.7	23.6	.....	39	34.5	24
Nitrogen as: albuminoid "	5.7	3.8	2.7	5.2	6.05	11.3	14.2	4.3	4.3	6
Nitrogen as: organic	18.1	10.7	11.3	29.0	.....	.....	.....	.....	.....	.....
Nitrogen as: total	39.6	26.5	19.0	40.2	.....	.....	.....	.....	.....	.....
Chlorine	64	30	47	63	123	.....	.....	132	267	170
Dissolved matters: total	312	185	232	548	715	1070	1045	870	1093	940
Dissolved matters: mineral	200	110	181	357	597	.....	.....	565	755	470
Dissolved matters: organic and volatile	112	75	51	191	118	.....	.....	305	338	470
Suspended matters: total	289	102	68	360	346	610	635	483	408	370
Suspended matters: mineral	63	27	15	178	164	240	.....	228	183	200
Suspended matters: organic and volatile	226	75	53	182	182	370	.....	225	225	170
Total solid matter: total	601	287	300	908	1061	1680	1680	1353	1501	1310
Total solid matter: mineral	263	137	196	535	761	.....	.....	793	938	670
Total solid matter: organic and volatile	338	150	104	373	300	.....	.....	560	563	640

* Estimated.

TABLE 5.—Estimated Quantities of Principal Constituents, in Grams per Capita Daily, of Sewage of Various Cities Classed According to the General Nature of the Sewage.

	Domestic sewage from small Massachusetts cities.				Domestic sewage and street refuse from the Metropolitan District of London.			Domestic sewage, street refuse, and trade waste, from manufacturing cities.					
	Framingham.	Gardner.	Marlboro.	Average.	North.	South.	Average.*	Huddersfield.	Leeds.	Leicester.	Manchester.	Worcester.	Average.
Oxygen consumed	17	13	9	13	24	25	25	67	47	40	55	44	50
Nitrogen as Albuminoid Ammonia	1.6	1.4	1.2	1.4	0.8	1.0	1	2.5	2.5	3.2	1.7	2.9	2.5
Nitrogen as Free "	5.9	5.9	3.3	5.0	7.0	7.8	8	4.4	5.3	.....	6.7	6.3	5.5
Nitrogen as Total	.....	.....	.....	9.7	.....	.....	13	.....	.....	.....	.....	.....	.....
Chlorine	18	11	20	16	24	60	24	50	.....	.....	47	35	44
Dissolved matters Total	86	69	100	85	157	248	157	204	240	236	260	308	268
Dissolved matters Mineral	55	41	78	58	102	172	102	245	.....	.....	130	201	178
Dissolved matters Organic and volatile	31	28	22	27	55	76	55	49	.....	.....	130	107	90
Suspended matters Total	80	38	29	49	87	92	87	142	137	143	102	202	145
Suspended matters Mineral	18	10	6	11	41	41	41	67	54	.....	55	100	69
Suspended matters Organic and volatile	62	28	23	38	46	51	46	75	83	.....	47	102	76
Total solid matter Total	166	107	129	134	244	340	244	436	377	379	362	510	413
Total solid matter Mineral	73	51	84	69	143	213	143	312	.....	.....	185	301	247
Total solid matter Organic and volatile	93	56	45	65	101	127	101	124	.....	.....	177	209	166

* The average is not a direct mean of data tabulated, but is given in round numbers in partial conformity with the data of Letheby.

TABLE 6.—Estimated Total Dry Sludge or Suspended Matter in Various Sewages.

Place.	Parts per million.	Grams per capita daily.	Tons per million gallons.	Tons per 1 000 population per annum.
Framingham, Mass.	289	80	1.20	32
Gardner, "	102	38	0.42	15
Marlboro, "	68	29	0.28	12
Worcester, "	360	202	1.50	81
London (North), England	483	87	2.00	35
London (South), "	408	92	1.70	37
Huddersfield, "	346	142	1.44	57
Leeds, "	610	137	2.54	56
Leicester, "	635	143	2.64	57
Manchester, "	370	102	1.54	41

Preparatory Treatments.—Probably the most important line along which evidence has recently been accumulated in this country, is that of different preparatory treatments by which the sludge or suspended matter may be eliminated from sewage (after proper screening) before its treatment by filters or the final process of purification.

Supervision of Plants.—Regarding the supervision or management of purification works in America, substantial progress has been made, and while at many of the smaller plants the supervision is not as efficient as it should be, there are a good many plants which are now carefully operated. At some of them, as at Worcester, Mass., Brockton, Mass., and Providence, R. I., superintendents and trained analysts are provided, who supervise and direct the various operations, using the results of frequent analyses as a guide. Speaking generally, the sewage purification works in New England, Ohio, Illinois and Iowa are examined, and analyses made, either by State Boards of Health or by officials of State Universities. Studies of importance upon the operation and management of disposal works in these and other States, are of course made by city officials and individuals in repeated instances.

Broad Irrigation or Sewage Farming.

This method of purification refers to those filtration areas which are cultivated, and to which the rate of application (intermittent)

of sewage is kept so low that it does not interfere with the raising and harvesting of crops.

Strictly speaking, this method is not in general use in this country except in the Far West, although there are a good many intermittent filter plants in the East where crops are raised on portions of the area. Some profit results from the use of these filter areas for agricultural purposes, but this seems to be a small and incidental feature. There appears to be no good reason, in the opinion of some, why crops should not yield in the East a sufficient revenue in some cases to cover perhaps the cost of caring for the plant, and even in some instances to provide some interest on the investment, as is the case with works in the West and in Europe. So far as known, this has rarely if ever been the case here.

Broad irrigation in the East is rendered less advantageous by the heavy rainfalls which occur quite frequently during the late summer and early autumn, and which are likely to result either in the discharge of the sewage in an unsatisfactory manner into some neighboring brook, or in the application of such large doses to the rain-saturated filter beds that the crops are seriously injured, especially at times of harvesting. Consequently, at most of the eastern plants, crops are raised on a portion of the filter area only. Exceptions may be found where it has been necessary or advisable to purchase comparatively large tracts of inexpensive land when first laying out the works, and where the rate of filtration is very low.

In the Far West, where the rainfall is very small as an average (12 to 15 in. per annum), and confined to a small portion of the year (2 to 4 months), irrigation with either water or sewage is essential for the success of agricultural pursuits. There, sewage is used for purposes of irrigation with considerable success at a number of places, but the sanitary question of disposing of the sewage seems to be quite incidental.

The crops raised on sewage farms include nearly all those ordinarily attempted in the section where the plant is located. Among them may be mentioned pease, beans, tomatoes, corn, cabbages, turnips, grass, alfalfa, various fruit trees, etc. In some instances a popular prejudice against vegetables and crops raised on sewage farms has been encountered; and at some places difficulty has been encountered in leasing city lands to be used for sewage irrigation.

While available evidence does not record frequent trouble so far as known from the use of vegetables grown on sewage farms, it is the belief of the writer that vegetables used on the table in a raw condition, such, for instance, as lettuce and celery, should be excluded from these crops. Vegetables which are always cooked before being served are not apparently injured by sewage irrigation, so far as the sanitary aspect of the matter goes.

Sub-Surface Irrigation.

Twenty years ago the method of disposing of sewage by applying it to land through pipes laid beneath the surface, usually in trenches, was widely used for small isolated communities, institutions, hotels and the like. Recently the only town works which have been built after this general system, so far as known, are at Danville, Ky.

The trouble with sub-surface irrigation is of course due to the clogging of the drains and the expense of digging them up at comparatively short intervals, cleaning them and relaying them. This clogging is caused largely by fats and suspended solids in the sewage. By the use of effective grease traps, and thorough preliminary treatment for the removal of suspended matter by sedimentation or septic treatment, this method has much merit, in the opinion of the writer, for some small projects. The cost of digging up trenches, cleaning the pipes and replacing them at infrequent intervals is sometimes a less serious factor than the cost and bother of frequent attention in operating surface filter plants so that there will be no objectionable odors.

So far as municipal sewage disposal works are concerned, there is very little in this method to commend its use.

Intermittent Sand Filtration.

This method consists in applying comparatively small volumes of sewage to areas of porous sand, allowing the sewage to drain from the pores of the material, which fill with air, and in repeating the dose of sewage some hours or days later. The process is essentially a biological one, and has been described as allowing sewage

to remain in the pores of the sand filter for a sufficient time, in the presence of air and the necessary bacteria, including nitrifying organisms, which become established on the sand grains. This treatment results in a large portion of the putrescible organic matter being converted into stable mineral matter (nitrates). Continuous filtration of sewage with the pores of the sand filled with liquid like the continuous filtration of water on sand beds, is impracticable because it prevents the entrance of sufficient air to bring about oxidation. Hence putrefaction within the filter would result quite soon, nitrification would disappear and the process would consist simply of removing suspended matters by straining. The latter process has its field of usefulness, but it is quite distinct from intermittent or biological filtration.

General Efficiency.—A greater degree of purification, generally speaking, can be obtained by this process than by any of the others in use (excepting the allied methods of broad and sub-surface irrigation). When the filters are operated under favorable conditions the effluent is practically free from turbidity and odor; and it is stable; that is, it will not decompose upon standing. Filtered sewage usually contains only about 1% or so of the number of bacteria present in raw sewage, the degree of removal depending much on the kind of sand.

Kind of Material.—Regarding the effect of the kind of material, the best results, all things considered, are obtained from medium or fairly coarse sand. Fine materials, like ordinary loam and river silt, allow the pores to remain filled with water by means of capillarity, and sufficient air cannot enter the pores of the material to give good results, except at very low rates. With materials like clay, fine loam and peat, this method of purification is impossible.

With coarse-grained materials, on the other hand, such as gravel, or coke, or broken stone of similar size, there is obviously no difficulty in passing large quantities of sewage through such filters, but with the ordinary method of application it passes through so quickly that the degree of purification is not satisfactory. Consequently the use of coarse-grained filters (other perhaps than as mere strainers) requires the flow of sewage to be especially regulated. This may be done by the fill and drain method, usually spoken of

as contact filtration, or by applying at the surface very small doses at frequent intervals, a process variously referred to as spraying, sprinkling, trickling, or continuous intermittent filters. These coarse-grained rapid filters which have been discussed so much during the past 10 years and frequently described as bacterial filters, have really no more claim to the latter name than have intermittent filters, of which they properly form a class. In this paper, however, they are considered separately as a matter of convenience.

The comparative effect of different kinds of filtering materials, as regards the quantity of sewage treated and the degree of purification, is well illustrated by the results in Table 7, containing the average data of the more important filters which have been operated during the past 15 years at the Lawrence Experiment Station, and which in general correspond to the results obtained from large plants of this type in New England.

Depth of Material.—As to the effect of depth of filtering material, it is to be stated that the majority of work is done by intermittent sand filters at the surface and in the upper 2 or 3 ft. A greater depth than this immediately above the underdrains is desirable, to prevent sewage reaching the effluent pipes before purification is properly effected, but, generally speaking, sand filter beds (not coarse-grained material) in practice having greater depth, seem to possess very little advantage over the ordinary 2- to 3- ft. depths.

Underdrains.—There is no general rule regarding underdrainage other than that drains should be provided to assist properly in the prompt removal of the sewage from the pores of the filtering material, and thus allow the latter to fill with air. When the ground water reaches within a few feet of the surface, or when artificial beds are built on a fairly impervious bottom, the drains are very important, but they are practically of no benefit where the beds consist of deep natural layers of porous material.

Stratification.—It is of importance in laying out sand filter beds that the materials from top to bottom be fairly uniform in size of grain. If fine sand, loam or clay remains above coarse sand, the latter is of limited benefit for filtration, because a water seal is formed at the bottom of the fine layer, due to the liquid held in the pores by capillarity, and air is excluded from entering the sand. If coarse sand overlies fine material near the surface, clogging

TABLE 7.—Average Data of Principal Intermittent Sand Filters Operated During the Past 15 Years at Lawrence, Arranged to Indicate the Differences in Rate of Filtration and in Composition of Effluent, Due to Differences in Kind of Filtering Material.

Sewage and effluents.	Filtering Material. Kind.	Depth, in inches.	Effective size, in millimeters.	Years covered by averages.	Average number of gallons applied per acre daily for 7 days in the week.	Parts per Million. Oxygen consumed.	Nitrogen as: Ammonia. Albuminoid.	Ammonia. Free.	Nitrites.	Nitrates.	Chlorine.	Bacteria, per cubic centimeter.
Sewage*.....	.....	.....	.....	1888–1902	.....	39.4	5.77	25.9	0.0	0.0	80.4	2 025 000
Filter No. 1...	Coarse sand.....	63	0.48	1888–1902	61 980	5.8	0.544	5.30	0.215	21.44	81.0	37 500
" " 2...	Fine sand.....	60	0.08	1888–1902	32 184	2.8	0.213	3.53	0.129	21.98	79.0	400
" " 4...	River silt with trenches of coarse sand.....	60	0.04	1888–1902	20 886	2.6	0.206	2.04	0.026	18.90	73.4	200
" " 5*a*..	Gravel.....	60	1.40	1891–1897	67 422	6.6	0.862	6.10	0.304	21.02	94.4	128 700
" " 6...	Mixed gravel and coarse sand.....	44	0.35	1888–1902	48 618	4.6	0.399	4.58	0.338	21.00	80.0	10 200
" " 7...	Same as No. 6, but covered with layer of loam.....	44	0.35	1888–1894	19 380	1.5	0.154	2.04	0.064	14.37	60.6	1 100
" " 9*a*..	Medium fine sand.....	60	0.17	1891–1902	58 688	4.8	0.462	7.35	0.099	23.60	85.3	12 400
" " 10...	Mixed fine and coarse sand.....	60	0.35	1894–1902	55 458	4.2	0.400	4.65	0.177	27.80	93.8	6 700

* The station sewage gradually grew stronger during this period of 15 years as indicated by the chlorine.

sooner or later takes place at the junction and air is similarly excluded.

Nitrification and Temperature.—While it may be possible to obtain an effluent from intermittent sand filters which is fairly clear, free from odor and incapable of putrefaction, without nitrification, the latter process is, generally speaking, the controlling feature of this method of purification.

Temperature has a marked influence upon nitrification, especially upon the time required for its establishment. As stated in the 1894 Report of the Lawrence investigations, nitrification in the early summer becomes established in less than a week after new sand is first treated with sewage, whereas a period of 2 or 3 months is necessary with similar filters started in the winter. A difference of a few degrees in the sewage, say between 42 and 45° fahr. makes much difference with the nitrifying action of intermittent sand filters.

Biological Construction.—The expression "period of biological construction" was used in the Lawrence reports some years ago, meaning the period which was required for the establishment of nitrification in new filters, or in those in which it had disappeared. Frequently it happens that the ordinary construction of disposal works is completed late in the autumn, and it is not unnatural that sewage should then be applied to the beds. This is frequently a great disadvantage, in that it clogs the filtering material during quite a number of months prior to the establishment of active nitrification, and seriously handicaps future operations. This same comment holds true with regard to septic treatment, as well as the various kinds of biological filters.

Winter Treatment.—During the long cold winters of the northern section of this country, intermittent sand filters have to be operated with considerable judgment in order that their efficiency is not impaired seriously. At best the quality of the effluent is somewhat poorer in winter than during warm weather (see Lawrence Report. 1894, p. 513). Speaking generally, it has been found in practice that it is less difficult to maintain the surface of filter beds sufficiently free from frost so as to allow the sewage to enter them, than was first indicated by the test filters at Lawrence having gravel underdrains under the entire layer. To accomplish this, however,

it is necessary to apply the sewage in relatively large doses, thus concentrating a sufficient amount of heat to penetrate the frost. Much assistance has also been obtained by arranging the surfaces of the filter beds in alternate ridges and furrows, so that the sewage may be applied in the furrows. As many weeks go by without opportunity to remove any sludge from the trenches, there is a limit to the total quantity of sewage which can be so applied. Ice usually forms then upon the surface of the sewage and extends from ridge to ridge, thus forming a natural covering over the portion of the area which actually receives the sewage.

At Clinton, Mass., a portion of the filter beds is furrowed in this way, and a portion left untreated. In a general way their experience indicates the advisability of applying sewage, during winter weather, when the air temperature at 7 A. M. is above 15° fahr., to beds with flat surfaces at about double the summer rate for a single dose. When the temperature is below this, the sewage is applied to the furrowed beds at about four times the regular dose for one bed. This treatment is believed to be effective in keeping the filtering surfaces free from objectionable amounts of frost, but there are disadvantages in such special treatment (unless special care is taken), in that there is danger that some of the beds may not be treated with sewage at sufficiently frequent intervals to allow the nitrifying process to be maintained in an effective manner.

Capacity of Sand Filters.—Rates of filtration within certain limits mean but little in regard to filter capacity, owing to differences in the strength of sewage. Judging from experiences at Brockton (separate sewers), and Pawtucket (combined sewers), 1 500 persons per acre is about all that ordinary sand beds will take care of, and then trouble from clogging during long severe winters is apt to occur unless some sewage is diverted from the filters at intervals. At both these plants the sludge is received on the filters but applied to separate beds. At most filter plants receiving raw sewage there are from 500 to 1 000 persons actually connected to the sewers for each acre of filters. Where the sewage receives effective preliminary treatment each acre of filters may perhaps suffice for 2 500 to 4 000 persons, but the data upon this point from actual practice are still very meagre. Higher rates than indicated above are reported from some places, but it is generally found that such

high rates have to be discounted considerably on account of the raw sewage being very weak, or that the rates refer to summer and not winter conditions.

Relation between Strength of Sewage and Rate of Filtration.—The rate of filtration bears in a general way an inverse relation to the strength of the sewage. In other words, as was shown at Lawrence (1901 Report, page 306), if one sewage contains one-third as much organic matter as another, it can be filtered, under equal conditions, at about three times the rate, and with substantially the same quality of effluent in each case. Especially valuable in considering this proposition are data obtained from filtering sewage from the same source, but from which organic and suspended matters have been removed, prior to filtration, in different amounts and by different methods. Such data are contained in Table 8, where are given the average results of investigations made at Lawrence during many years from a series of filters containing approximately the same size of sand, and to which was applied, in one instance, the raw station sewage and, in others, the same sewage after it had been partially treated by chemical precipitation, sedimentation, septic action, straining through coke and other ways. With the quality of the effluent approximately the same, it is seen that the rates of filtration are much higher in those filters receiving a partially purified sewage.

Removal of Surface Clogging.—The suspended matters in sewage naturally are retained for the most part at and near the surface of the sand layer, and it is obvious that they would form an almost impervious layer ultimately if the surface were not freed from such matters. Air would thus be prevented from entering the pores of the material, and the process would be seriously interfered with. Frequent raking and harrowing, and occasional plowing and scraping, are required to remove clogging due to the accumulation of sludge.

Some of this suspended matter is of a mineral nature (see Tables 5 and 6), and it is of course impossible for it to be removed by nitrification. Naturally, this accumulation becomes sufficiently great in time, and it has the effect of partially closing the voids and making the filtering material similar in character to new material of a much finer size of grain. This is well shown

TABLE 8.—Average Data Showing Rates of Filtration and Composition of Influents and Effluents of 5-Ft. Filters at Lawrence Containing Medium Fine Sand, and to which was Applied the Station Sewage after Receiving Various Kinds of Preparatory Treatment.

Filter Number.	Effective size of filtering material, in millimeters.	Preparatory treatment received by influent.	Years covered by averages.	Average number of gallons applied per acre daily for 7 days in the week.	Influent. Parts per million. Oxygen consumed.	Nitrogen as ammonia. Albuminoid: Total.	Nitrogen as ammonia. Albuminoid: Susp.	Nitrogen as ammonia. Albuminoid: Free.	Chlorine.	Bacteria, per cubic centimeter.	Effluent. Parts per million. Oxygen consumed.	Nitrogen as: Ammonia. Albuminoid.	Nitrogen as: Ammonia. Free.	Nitrogen as: Nitrates.	Bacteria, per cubic centimeter.
9*a*....	0.17	None.....	1892–1902	58 688	40.0	7.20	3.09	35.0	87.5	2 299 000	4.8	0.462	7.35	23.60	12 400
12*a*....	0.19	Filtered through coarse gravel, aerated..	1892–1897	503 030	10.1	1.43	.....	7.1	92.0	273 700	2.4	0.214	2.57	20.46	1 500
13*a*....	0.19	Sedimentation.....	1893–1897	177 049	30.6	4.27	1.61	31.8	98.4	2 100 000	2.9	0.324	4.43	24.66	4 300
14*a*....	0.19	Strained through coke.....	1894–1899	236 587	22.0	3.10	0.98	28.8	93.2	1 194 000	2.9	0.248	2.04	25.40	1 300
19....	0.17	Chemical precipitation.....	1893–1897	188 065	20.9	2.80	0.81	30.8	93.8	924 000	2.6	0.266	3.59	27.14	2 400
100....	0.26	Septic treatment.....	1898–1902	208 024	26.3	3.19	1.21	36.2	97.2	743 100	7.5	0.731	7.79	27.90	62 900
116....	0.17	Septic treatment.....	1894–1902	184 235	30.0	3.51	1.03	38.1	86.1	881 800	3.6	0.287	3.24	31.40	1 600
118....	0.23	Septic treatment, aerated.....	1899–1902	212 253	32.4	3.56	1.13	37.4	81.1	1 067 500	6.8	0.562	5.19	26.30	12 000

by the reports from Lawrence, which state that in 1902 the upper 6 in. of Filter No. 1 after 15 years' service had an effective size of 0.30 mm. as compared with 0.48 mm. when the sand was new. Below 9 in. from the surface this sand is of the original grade.

No matter how low the rate of filtration may be, it seems obvious from a theoretical standpoint that suspended mineral matters and humus will ultimately require the removal of the surface layer of all sand filters. Whether in the long run the amount of material to be removed (independent of the rate of filtration) bears a definite relation to the quantity of suspended matter applied to the filter bed seems probable, if not certain; and it is apparent that for short periods, say 10 years or less, the quantity of sand removed per million gallons increases quite rapidly with the rate of filtration, other things being equal.

The evidence upon this matter is considerably obscured by clogging and changes in the sand layer below the depths reached by the frequent rakings. It is also complicated by differences in the character of the sewage, the full significance of which is not now understood.

The last annual report from Worcester, Mass., indicates that the fairly clear effluent from the chemical precipitation works may perhaps not be filtered at a higher rate than ordinary crude sewage. This is at variance with the general experience at Lawrence, where chemical precipitation was effected by sulphate of alumina, as indicated by the data of Table 8, and is largely caused by clogging at and near the surface due to lime and iron in the clarified sewage applied to the Worcester filters.

The cost of operating intermittent sand filters during the earlier years of their life, including all labor in taking care of the beds, regulation of gate valves, the removal of sludge from the surface, etc., at a number of plants is given in Table 9.

Plain Sedimentation.

The deposition of suspended matters, particularly those of a mineral nature, in tanks or basins is a method of sewage treatment preparatory to filtration which has not been studied in this country with the thoroughness which some local conditions seem to warrant. The removal of suspended matters in this way facilitates a higher

rate of filtration. The difficulty in carrying out the process, however, on a basis comparable to settling tanks used in the clarification of muddy river waters, is that the sediment contains so much organic matter that it is necessary to remove the sediment frequently before putrefaction becomes too active, or the process no longer becomes one of simple sedimentation, but a mixed one of sedimentation and the septic treatment. The features of the latter process are treated as a separate topic later.

TABLE 9.—Memoranda showing the Cost of Labor in Operating certain Intermittent Sewage Filters.

Place.	Population connected to sewers.	Sewage flow in millions of gallons.		Area of filter, in acres.	Cost of Labor.		Period.
		Per annum.	Average daily.		Per million gallons.	Per capita per annum.	
Brockton, Mass.....	30 000	320	0.877	21.5	$11.00	$0.12	1903.
Clinton, "	11 000	286	0.785	23.7	8.29	0.22	1902.
Concord, "	1 200	110	0.300	3.3	3.15	0.29	1901-03.
Danbury, Conn.....	8 000	220	0.600	10.	9.00	0.25	1903.
Gardner, Mass.*.....	4 500	90	0.250	2.25	9.30	0.19	1903.
Meriden, Conn.....	20 000	1 010	2.75	11.	3.65	0.185	1903.
Pawtucket, R. I.**....	5 100±	.....	0.100±	2.36	55.00	0.58	Average 1894 to 1902.
Spencer, Mass.....	3 000	140	0.375	9.3	5.84	0.27	1903.
Worcester, "	.....	510	1.400	13.	6.79	0.30	1903.

* Refers only to new plant, built in 1901, but includes labor on coke strainer.
** Includes special work on test filters, etc.

At most intermittent sand filters in New England it is found advantageous to apply the sludge, so far as possible, to but a limited area of filtering surface, because it can then be removed at less cost than if it reaches the entire area.

Where there is a gravity flow to the filter beds, small tanks have been provided for the removal of coarse sludge. They are usually so small, however, holding the average flow for about 1 hr. or so, that they are not much more than grit chambers.

At places where sewage is pumped to disposal fields it is usually the custom to build a receiving tank or reservoir, in which the night flow is allowed to accumulate. The cost of such a basin, which allows all the pumping to be done in half a day or less, is less than

that of maintaining a pumping station in continuous operation. This is the plan at Framingham, Mass., Brockton, Mass., and Clinton, Mass., where the receiving basins have a capacity roughly approximating the average daily flow. The sludge which collects in a considerable degree at the bottom of such tanks is usually discharged upon special beds.

At Pawtucket, R. I., where there are two shallow tanks having a combined capacity approximating the daily flow of sewage, the reports of George A. Carpenter, M. Am. Soc. C. E., City Engineer, show that in 1901 the accumulated sediment or sludge averaged about 4.87 tons per million gallons. This sludge was drawn every other day from a tank to sludge beds, and was raked from the surface of the beds.

At Brockton, Mass., the sludge or heavier matters which accumulate on the bottom of the storage reservoir represents about 10 to 12% of the total pumpage, and is applied to special filter beds for the purpose, from which the solid matter is raked after about 15 to 20 doses. These air-dried rakings amount to from 5 to 8 tons per 1 000 000 gal. of sewage, equivalent to about 80 tons per 1 000 population per annum. They are sold to farmers for fertilizer for $150 per annum.

At Worcester, Mass., plain sedimentation in one of the large basins at the chemical precipitation works was carried on for about two months in 1903, and from the annual report of the Superintendent of Sewers for that year the following data are obtained. The basin holds 344 000 gal., and the daily flow through it averaged 1 000 000 gal., making the average period of sedimentation about 8 hours. The removal of suspended and total organic matter, as indicated by the albuminoid ammonia, was found to average 40.80 and 27.48%, respectively. The volume of wet sludge or deposit removed from the bottom of the tanks equaled 0.125% of the volume of sewage passed through it, or about 6.17 cu. yd. per 1 000 000 gal. The solid matter in this wet sludge amounted to 3.5 per cent. It was pressed without difficulty at a cost of $1.56 per 1 000 000 gal. of raw sewage, including handling of pressed sludge cake by trolley to the sludge dump. The other cost of sedimentation, labor and attendance, is given as $1.85 per 1 000 000 gal.

Chemical Precipitation Works.

The fundamental principles of this process of sewage treatment, so far as they relate to efficiency and to the comparative merits and economy of different precipitants, were carefully studied at Lawrence by Allen Hazen, M. Am. Soc. C. E., and published in the special report of the Massachusetts State Board of Health, 1890, Part II, pages 737 to 795. Knowledge upon matters therein considered has not materially changed since their publication, although information has become more definite as to the practical aspects of the deposition of the coagulated matters, and especially with reference to the treatment of the sludge.

As regards general efficiency, this treatment will ordinarily remove from 50 to 55% of the total organic matter, and in the neighborhood of 90% of the total suspended matter. The bacterial removal is usually about 80 to 90 per cent.

The effluent of chemical precipitation works is ordinarily not stable; that is to say, it putrefies upon standing when unmixed with water containing a considerable proportion of dissolved oxygen. The latter constituent is ordinarily absent from the effluent of chemical precipitation works unless added by special aerating devices.

Although both the sludge and the effluent of chemical precipitation works will putrefy, it is quite rare for seriously objectionable odors to appear around the plants if they are well managed, especially as regards the frequency with which the sludge is removed during warm weather. No deodorants are used except at a number of plants in and around New York, built after the Power patents, and where chlorine is applied to the partially settled sewage.

Copperas and lime are the chemicals which seem best adapted, generally speaking, to the economical coagulation of sewage. In some cases municipal sewages contain manufacturing refuse so as to modify this general statement. For instance, at Worcester, Mass., the city sewers receive large quantities of pickling liquor from steel plants, so that the sewage, as it reaches the precipitation works, already contains excessive quantities of sulphate of iron.

Sulphate of alumina is well adapted for use as a precipitant but is more expensive than those mentioned, and, according to the experience at the precipitation works of the Columbian Exposition

at Chicago, the sludge could be less readily pressed into cakes when it was used as a precipitant than when copperas and lime were used. Perchloride of iron is used at the several plants around New York built after the Power patents. This precipitant is efficient but expensive.

All the basins at the chemical precipitation works in this country, as far as known, are operated on the continuous displacement, and not on the fill and draw, plan. Their nominal capacity ranges ordinarily from 30 to 50% of the average daily flow, disregarding the contents occupied by sludge.

Through the kindness of H. P. Eddy, Assoc. M. Am. Soc. C. E., Superintendent of Sewers at Worcester, Mass., and of Otis F. Clapp, M. Am. Soc. C. E., City Engineer of Providence, R. I., very full data are available showing the leading results of operation at these two principal chemical precipitation works, as given in Table 10.

In comparing these data it is to be borne in mind that at Worcester there is much pickling liquor in the sewage, thus requiring much lime to be added but no copperas. There is also tannery waste, which gives the effluent a somewhat discolored appearance. At Providence the sewage contains considerable waste liquor from dye-works, at certain periods of the day, and this gives the effluent there a discolored appearance, and not the fairly clear effluent which results from treating ordinary domestic sewage by this process. During the portions of the day when the raw sewage is strongest, copperas is used at the Providence works, but not at night. The smaller percentage of suspended matter removed at Providence, as compared with that at Worcester, is explained largely by the more thorough screening at Providence. In comparing the cost of treatment at the two plants, it is necessary to consider not only the greater repair account for the older plant at Worcester, but also the difference in the raw sewages, and particularly the difference in the local labor markets. At Providence all ordinary laborers are paid $1.50 for 10 hours; at Worcester the minimum wage is $1.85 for 8 hours, and some are paid more.

Sludge is ordinarily removed at each plant about once a week from the "roughing tanks" (in which the sewage first enters and the coarser matters are precipitated). The "finishing" tanks, through

which the sewage last passes and in which the finer particles are deposited, are cleaned once in two or three weeks, depending somewhat upon the advantageous management of the sludge disposal plants.

The pressed sludge cake is disposed of at Worcester and Providence by conveying it to vacant land in the general neighborhood of the disposal works. This is hardly a permanent method of disposal of the matters removed from the sewage, as this sludge cake accumulates at the rate of about 4 to 5 cu. yd. per 1 000 000 gal. of sewage treated. Ultimately it will become difficult or impossible to dispose of such accumulations in this way near large communities.

TABLE 10.—Summary of Principal Results of Operation of Chemical Precipitation Works at Worcester and Providence, 1903.

	Worcester.	Providence.
Population connected to sewers, estimated	122 000	170 000
Average daily sewage flow, total, in millions of gallons	15.55	20.38
" " " " " , treated, in millions of gallons	14.39	20.00
Total annual sewage flow treated, in millions of gallons	5 250	7 300
Applied lime: Pounds per million gallons	871	606
Applied lime: Grains " gallon	6.1	4.2
Applied copperas: Pounds per million gallons	0	65
Applied copperas: Grains " gallon	0	0.46
Gross capacity of basins, in millions of gallons	5.5	11.1
Percentage of removal: Total organic matter by albuminoid ammonia	51.69	49.80
Percentage of removal: Suspended organic matter by albuminoid ammonia	91.58	82.54*
Wet sludge: Average gallons pressed daily	67 200	95 600
Wet sludge: Percentage of total sewage flow	0.4671	0.4776
Wet sludge: Average percentage of dry solid contents	7.44	5.37
Wet sludge: Average pounds of lime added per one thousand gallons	33.5	23.6
Pressed sludge cake: Tons daily	69	76
Pressed sludge cake: Percentage of dry solids	30.3	28.25
Dry solids in sludge: Tons daily	20.8	21.4
Dry solids in sludge: " per million gallons	1.45	1.07
Dry solids in sludge: " " 1 000 population per annum	62	46
Cost of sludge pressing and disposal: Per ton of dry solids	$3.39	$2.27
Cost of sludge pressing and disposal: " million gallons sewage flow	4.91	2.44
Cost of chemical precipitation—labor and supplies—per million gallons	4.01	3.31
Total cost of operation: Per million gallons	8.92	5.75
Total cost of operation: " capita connected to sewers per annum	0.384	0.248
Cost per ton: lime	6.60	6.90
Cost per ton: copperas	.....	7.80
Minimum wage per hour for laborers	0.29⅛	0.15

* Providence sewage well screened before treatment.

Septic Treatment.

This is a modification along biological lines of plain sedimentation, and consists in general in allowing the accumulated deposits to remain within the settling tank, where bacterial action under favorable conditions causes putrefaction and thereby the liquefaction, and ultimately the gasification, of a substantial proportion of the suspended organic matter.

In a rough way it may be said that of the matter suspended in ordinary municipal sewage, about one-third passes through the septic tank and appears in the effluent; about one-third is liquefied and gasified; and the remaining third, consisting chiefly of suspended mineral matter, remains within the tank and ultimately requires to be removed and disposed of as sludge. The efficiency of the septic treatment depends to a very large degree upon local conditions, especially the composition of the sewage, and each of the three ways above noted as to the disposition of suspended matter may show a range of from 15 to 50% of the total, instead of the general average of 33⅓% as stated above.

The efficiency of this treatment consists of more than the removal of sludge or suspended matter from sewage going to the filters, as it brings about a partial mixing of sewage of widely varying strength as it flows at different hours of the day, and ordinarily it causes the organic matter to be broken down into simpler forms, which are believed to be more readily treated by filtration.

A few years ago the idea existed in the minds of some that the septic treatment was a complete process of purification by itself. Obviously this is not correct, as it removes, generally speaking, less organic matter (ordinarily about 40%) than does the chemical precipitation method, although there are some exceptions to this latter statement.

The effluent from a septic tank never contains dissolved oxygen after the process is normally established, and it goes without saying that the effluent is not stable; that is, it putrefies (or, better said, continues to putrefy) when allowed to stand unmixed with water.

The most practicable field for the septic treatment seems to be in connection with the treatment of strictly domestic sewage in which suspended mineral matter is present in only a very small

amount. In sewages where the suspended mineral matter is an important factor, it is highly desirable to eliminate from the sewage, preparatory to septic treatment, the coarser mineral sludge by means of plain sedimentation tanks, from which the sludge is removed from time to time before putrefaction sets in.

Regarding the period of treatment best adapted for the septic process, or, more accurately stated, the size of tank or basin to be used, the evidence is not conclusive, as the individuality of local conditions exerts a marked influence. In a general way the tanks should have a capacity equal to 12 to 24 hours' flow at the average rate.

The idea is sometimes advanced erroneously that the septic treatment of sewage is confined to the period occupied by the flow of the sewage through the tank. This is not so, as the controlling features are that the rate of flow, or velocity, must be such that there is deposited on the bottom of the tank a substantial proportion of the matters in suspension. In this accumulated sediment upon the bottom of the tank bacterial action becomes established, which gradually converts the suspended organic matter into dissolved matter, and the latter in turn is converted to gaseous constituents.

The over treatment of sewage by the septic process is a factor encountered at the small plant at Andover, Mass., and resulted in an effluent which with difficulty could be filtered and nitrified. This complication developed when the sewerage system was only in partial use and the sewage was abnormally old and "stale" when it reached the disposal field. It could apparently be remedied by aeration of the septic effluent prior to its filtration. Presumably this feature will disappear in a large measure when more connections are made to the sewers already built, and the sewage is fresher when it reaches the field.

The odors in the neighborhood of septic tanks are usually noticeable at some little distance, although ordinarily they are not seriously objectionable even at the tanks themselves. With some kinds of sewage, however, this is not the case. In general, bad odors result from the septic treatment of those sewages containing relatively high amounts of sulphur compounds, such as the acid sewage at Worcester. A similar result is possible, in a less degree, with the sewage from communities in which the water is hard, due to sul-

phates of lime and magnesia. Where sulphate contents are fairly low these odors, perhaps somewhat allied to sulphuretted hydrogen, are generally not so conspicuous.

Covers for septic tanks do not seem to facilitate to a marked extent the septic process, as the accumulated scum or crust generally present on the surface of the liquid serves that purpose in a measure. It does not wholly serve it, however, as severe windstorms are apt to bring about disturbances, scattering the scum and resulting in bad odors. The question of covers, to the mind of the writer, is still unsettled, and depends largely upon local conditions.

The influence of temperature upon the septic process is marked, and in a rough way follows the influence of temperature upon nitrification as has been outlined in connection with intermittent filters. The relation between temperature and septic action has been shown by Messrs. Kinnicutt and Eddy by the determinations by months of the relative volumes of evolved gas from a closed septic tank at Worcester, Mass., during 1902, as given in Table 11.

TABLE 11.—Relative Volumes of Gas Evolved by Closed Septic Tank at Worcester, Mass., 1902.

Month.	Mean Temperature, in Degrees, Fahr.		Volume of Gas.	
	Sewage.	Effluent.	Percentage of sewage flow.	Percentage of yearly mean.
January	48.16	46.58	1.171	30
February	47.01	45.74	2.448	62
March	46.68	45.86	1.866	48
April	49.15	49.10	1.996	51
May	55.43	55.77	3.979	100
June	59.54	61.52	5.837	148
July	64.22	63.68	5.521	140
August	66.38	65.84	6.624	167
September	66.56	64.76	6.689	170
October	61.16	60.08	4.550	116
November	57.02	55.76	4.528	115
December	49.28	48.56	2.572	65
Mean	55.88	55.27	3.939	100

This escaping gas on an average is composed of about 75% marsh-gas, 15 to 20% nitrogen, and the remainder mostly carbonic acid and hydrogen. Gas from the highly septicized sewage at Andover, however, contained 29% marsh-gas and 61% nitrogen.

The period of time required for septic action to become established in new or clean tanks ranges generally from about two weeks to two months, depending upon the temperature and composition of the sewage. Acids and trade wastes have in general a retarding influence upon this bacterial process.

As the effluent leaves the septic tank it contains much gas in dissolved form, which requires considerable air for its oxidation. This is well shown in the Lawrence report of 1900, p. 387, where is described the rapid absorption of oxygen by a septic effluent, both without and with sterilization by chemicals, but where the absorption by the same effluent was nil after expelling the gases by heat. Aeration of the effluent of the septic tank facilitates filtration and makes higher rates feasible, but on the other hand, it has its drawbacks on the ground of producing under some conditions seriously objectionable odors.

The amount of suspended matter in the effluent varies considerably, due to a variety of factors, among which may be mentioned the character of suspended matter in the raw sewage, temperature, amount of sediment in the tank, and evolution of gas which at intervals belches forth and carries with it much sludge. The suspended matter is sufficient in amount sometimes to make it worth while to consider its removal by further preparatory treatment prior to filtration, that is, by settling basin or roughing filters. The suspended matter is ordinarily quite finely divided, however, so that its removal is not easy.

This process by no means eliminates the sludge question, and, generally speaking, septic tanks treating sewage require cleaning several times a year, although there are exceptions, particularly where house sewage alone is treated. A rough idea of the sludge accumulations in septic tanks may be obtained by dividing by three the quantities of total suspended matters in different sewages as given in Table 6. At Plainfield, N. J., the City Engineer, Mr. Gavett, reports that during a 5-month period between cleanings, the wet sludge removed from the septic tank at that city was about

4.5 cu. yd. per 1 000 000 gal. The sludge from septic tanks is difficult to dispose of on a very large scale, unless carried to sea in vessels, as it cannot always be pressed advantageously into cakes as in the case of sludge from chemical precipitation works. For small or moderate sized plants it can be applied to land and composted.

Strainers, or Roughing Filters.

For many years special strainers of excelsior, straw and various other materials have been used in efforts to remove from sewage more or less of the solid matters. Benefit has been derived, no doubt, from some of these arrangements at manufacturing establishments, but for municipal sewage these earlier efforts at straining, as practiced some years ago at Atlantic City, N. J., and Long Branch, N. J., have been abandoned as impracticable. Unless the expense becomes relatively great it is understood that their efficiency is very small.

The use of roughing filters or strainers of fairly fine material has been studied at Lawrence for about 10 years. Coal and coke have been the materials most used in these studies, and it would seem that this method of preliminary treatment or clarification of sewage may have more merit than American engineers have generally been inclined to give it credit for. This is especially true where purification works have been located near a pumping station, and where the accumulated sediment or sludge at or near the surface of the strainers can, after air drying, be used for fuel purposes under boilers.

On a practical scale such strainers were put in use at Gardner, Mass., in 1901, where there are four strainers, each one-eighth acre in area. The material is 15 in. thick, composed of 6 in. of crushed stone and 9 in. of coke breeze. About 300 000 gal. of domestic sewage have been applied daily, with the result that about 70% of the total organic matter is removed in this way during the warmer season of the year. The surface requires cleaning about once in 10 days, the material removed equaling about 2 cu. yd. per 1 000 000 gal. Frost prevents the filters from being cleaned at such frequent intervals, and during the past winter these strainers went out of service early in January. Although it is necessary in this climate

to cover such strainers for winter service, it does not necessarily eliminate this treatment from practical consideration under some conditions.

Roughing Filters, or Strainers, with Enforced Aeration.

In 1892 investigations were begun at Lawrence with the artificial aeration of coarse gravel filters to which sewage at relatively high rates was applied, with a view of purifying it partly so that final purification could take place at a relatively high rate in an ordinary sand filter. These filters were continued in service for five years, and similar ones were tried, containing cinders, coke and other materials. Air was artificially drawn through the filtering material, in some cases in an upward direction and in others in a downward direction, but in all cases these filters clogged in a manner which indicated decisively that this artificial aeration, while beneficial to a certain degree, was not helpful in proportion to its cost unless power was available at nominal expense.

Colonel Waring tested at some length a similar device at Newport during 1894, which device was installed on a practical scale in connection with other portions of the Waring system at Willow Grove (near Philadelphia), East Cleveland, Ohio, and a number of small places elsewhere. So far as known, experiences on a practical scale lead to no conclusions other than that above stated in connection with the Lawrence investigations.

Contact Filters, or Rapid Filtration Through Coarse Material on the Fill and Draw Plan.

This method of filtration came to attention in England some 10 or 12 years ago, and has been used in this country sufficiently to demonstrate clearly that nitrification is possible at rates far in excess of those which can be used in ordinary intermittent sand filters. This method of treatment consists ordinarily of filling with sewage filters containing fairly coarse material, such as broken stone, coke and the like, allowing the filter to stand for a short period after the pores are filled with sewage, then slowly draining it. By this procedure nitrification is brought about and there is obtained an effluent which is fairly stable as to the residual organic matter

which it contains. That is, this type of filter will, under favorable conditions, provide an effluent that does not putrefy, although it is greatly inferior to the effluent of intermittent sand filters as regards turbidity, organic matter and bacterial contents.

These filters can be operated for a time on the basis of three complete cycles, or fillings, per day, although provision should be made for allowing the filters to rest for several days at a time now and then. When moderately free from clogging material, the rate of filtration will approximate roughly the cubic contents of the filter beds, assuming that the voids approximate one-third the total contents. Within certain limits their capacity is roughly proportional to their depth.

In practice it is found that it is essential that these filter beds be constructed with ample underdrains at the bottom, and that the material be of stable character, such as will not disintegrate. The percentage of voids in these beds ordinarily is in the vicinity of 50% when the material is new, but gradually they are reduced by compacting and by the filling of the voids by suspended matter until, in the course of time, the voids amount to 25%, or even as small as 20%, of the cubical contents.

The size of material best adapted to contact beds is believed to be about ½ in. average size, ranging from particles which will pass through a sieve with 1-in. mesh and be retained on a sieve of ¼-in. mesh. Coke and broken stone, with their rough surfaces, seem to be somewhat superior to gravel.

The loss of capacity of the voids is one of the most important features in conection with this type of filtration. By resting the filters, it is possible to have them dry out so that the accumulated sludge or organic matter will in part oxidize and nitrify, and in part crack, peel and pass from the filters with the effluent. Complete removal of clogging material is hardly feasible in this way. Further aid may be obtained by flushing the material in place.

This style of filter usually produces a quite turbid effluent, due in part to the matters detached from the filtering material and in part to the passage of suspended matter with the sewage through the filtering material.

Generally speaking, the suspended organic matter in the effluent is of a fairly stable character, that is, it will not putrefy on standing.

TABLE 12.—Summary Showing Average Lawrence Data Regarding Rate of Filtration and Efficiency of Contact Beds.

Filter number.	Filtering material. Kind.	Depth, in inches.	Size.	Years covered by averages.	Preparatory treatment received by influent.	Average number of gallons applied per acre daily for 7 days in the week.	Influent. Parts per million: Oxygen consumed.	Nitrogen as: Albumoid.	Nitrogen as: Free ammonia.	Chlorine.	Bacteria, per cubic centimeter.	Effluent, Parts per million: Oxygen consumed.	Nitrogen as: Albumoid.	Nitrogen as: Free ammonia.	Nitrates.	Bacteria, per cubic centimeter.
81...	Ashes and cinders.	54	?	1897–Oct. 1, 1898.	Strained through coke.	647 000	20.9	3.33	28.4	79.1	1 534 000	12.1	1.62	15.4	10.8	407 000
103...	Coke.	60	⅛ to ¼ in.	Mch. 1, 1898–1902.	Septic tank.	595 500	27.3	3.29	38.7	97.4	760 400	7.8	0.87	7.9	21.2	94 900
107...	Cinders.	24	Free from ashes.	1898–Oct. 1, 1899.	None.	553 000	34.5	4.59	23.8	67.8	1 840 000	15.7	1.68	13.4	5.4	445 000
108...	Coke.	24	Free from dust.	1898–June 1, 1900.	Contact to 1900, then coke strainer.	441 000	18.0	1.99	17.7	73.7	540 000	9.5	1.00	5.8	11.9	230 000
108*a*..	Coke.	48	Same as No. 108.	Aug.–Dec., 1900.	Strained through coke.	466 200	27.9	3.22	32.0	99.0	1 010 600	11.2	1.34	9.8	19.5	630 000
117...	Broken stone.	126	⅛ to 2 in.	May–Dec., 1899.	None.	1 626 000	42.5	5.19	30.2	77.2	2 084 000	10.9	0.79	6.0	18.8	144 000
135...	Broken stone.	214	¼ to 1 in.	May–Dec., 1900.	None.	1 206 000	49.5	5.56	37.8	102.6	2 947 000	13.3	1.74	20.3	3.4	438 000
137...	Broken stone.	?	½ to 1 in.	1900–1902.	None.	663 180	42.6	5.88	36.2	96.7	2 623 700	21.1	2.56	22.3	8.3	563 200
154...	Coke breeze.	48	?	Sept.–Dec., 1900	Septic tank.	487 020	45.4	6.59	58.7	116.7	2 234 000	14.9	2.32	42.3	3.0	356 700
163...	Coke.	54	Fine.	1901–July 1, 1902.	Contact No. 137.	609 000	21.2	2.36	24.3	97.8	429 000	10.3	1.36	12.0	14.6	336 000
164...	Coke.	54	Considerably finer than No. 163.	Jan.–June, 1901.	Contact No. 137.	655 560	20.4	2.40	24.2	101.4	383 800	9.4	1.15	8.6	21.7	210 300
167...	Broken stone.	48	Walnut.	Mch.–Dec., 1901.	Septic tank.	340 000	65.9	8.50	85.3	117.7	321 700	20.9	3.24	54.6	13.4	227 000
175...	Coke.	60	¼ to 1 in.	1901.	Strained through coal.	779 820	25.2	3.63	36.1	116.1	760 000	10.5	1.42	13.5	13.4	131 500
176...	Coke.	60	¼ to 1 in.	1901–1902.	None.	663 500	42.8	6.06	37.2	100.7	2 568 000	7.7	1.52	13.1	11.3	413 200

It is perfectly feasible to remove a considerable portion of this suspended matter in the effluents of contact beds by means of straining at a rapid rate through a filter, or by sedimentation.

In a number of places double contact beds are provided, whereby the effluent after single treatment is passed through a similar filter at a lower level and at a higher rate. At some places this is advantageous, but it seems doubtful whether it is a preferable method, under many conditions, to the use of a single contact bed operated at a lower average rate, using the same total area as with double filtration.

There seems to be no good reason why contact beds should be condemned on account of the fact that they clog up at times and require the materials to be taken out, and either put back after cleaning, or replaced with new material. It is certain that this type of filter is not a permanent one for any rate approaching those which have been used in this country. The most economical rate varies largely, no doubt, with local conditions, particularly the cost of constructing the beds. It is largely a question of balancing the increased cost of operation due to high rates with the increased capital charges due to constructing increased filter areas which permit of low rates.

Comparatively little information in precise terms is available in this country as to the cost or frequency of removing clogging, or as to the efficiency of contact beds on a large scale. In most cases these filters have been operated with quite dilute sewage, from which a portion of the sludge has been removed by the septic treatment or other means. It is to be stated, however, that at Plainfield, N. J., and other places, contact beds have been operated at rates approximating 500 000 gal. per acre daily for two or three years or more, with merely nominal cost for cleaning.

In Table 12 is given, in summarized form, the leading features of the investigations at Lawrence with contact beds.

Intermittent Continuous Filters, or Sprinkling Filters.

These filters resemble contact beds somewhat, although the material is usually of larger size, 1 to 3 in. Instead of filling the

pores of the material with sewage and allowing it to drain out, it is sprayed in the form of rain over the surface, either by moving sprinklers or by spraying from nozzles set in stationary piping. The severe winter weather in the northern portion of this country interferes seriously with these distributing devices. While this method has much merit for southern towns and cities, its applicability is somewhat uncertain at present in the North on account of this question of distributing devices, although experiences at Madison, Wis., and elsewhere, indicate that successful results may follow the application of sewage to coarse-grained filters in small but frequent doses through lines of perforated tile pipe laid quite close together, and covered to protect them from cold weather.

The rate of filtration by this method is somewhat greater than that which can be maintained in contact beds with an equal quality of effluent as to putrescibility. This is due to the fact that the applied liquid is better aerated, which is also true of the voids in the filtering material, which seem to free themselves to a further degree of the accumulated sludge than in the case of the contact beds. The effluent of this type of filter is generally less turbid than that of contact beds, and the suspended matters, according to the Lawrence experiences, as reported by Mr. Clark, are of a more stable character and can be removed more readily by settling than in the case of those from contact beds. Bacterially these filters give better average results than contact beds, although in this respect all coarse-grained rapid filters are much inferior to the ordinary intermittent sand filter.

In the South this method is probably somewhat cheaper as well as more efficient than contact beds, but in the North this question is apparently an open one until more study is given to designs for applying sewage satisfactorily during freezing weather. While these devices are more expensive than those required for contact beds, it is not to be forgotten that with this method it is not imperative to place the filter beds in water-tight basins,—that is, retaining walls may be omitted.

The evidence now available as to rates and efficiency of this type of filter as studied at Lawrence is summarized in Table 13.

TABLE 13.—Summary Showing Average Lawrence Data Regarding Rate of Filtration and Efficiency of Intermittent Continuous Filters.

Filter number.	Filtering material.			Years covered by averages.	Preparatory treatment received by influent.	Average number of gallons applied per acre daily for 7 days in the week.	Influent.					Effluent.				
							Parts per million:					Parts per million:				
	Kind.	Depth, in inches.	Size.				Oxygen consumed.	Nitrogen as: Ammonia. Alb.	Nitrogen as: Ammonia. Free.	Chlorine.	Bacteria, per cubic centimeter.	Oxygen consumed.	Nitrogen as: Ammonia. Alb.	Nitrogen as: Ammonia. Free.	Nitrogen as: Nitrates.	Bacteria, per cubic centimeter.
134...	Broken stone.	60	¼ to 1 in.	1900-1901.	Septic tank (anaerobic broken stone).	1 097 700	19.2	1.78	40.2	104.7	391 300	10.3	1.07	21.8	16.41	67 400
135...	Broken stone.	216 and 144*	¼ to 1 in.	1900-1902.	Strained through coal.	1 349 200	28.4	3.66	43.5	90.7	829 600	13.2	1.53	20.6	18.60	160 800
136...	Broken stone.	216 and 144*	¼ to 1 in.	1900-1902.	Septic tank.	1 172 100	25.4	3.08	44.8	109.8	676 300	13.6	1.52	22.6	21.30	65 700

* Depth of material reduced in June, 1900.

Automatic Devices for the Application of Sewage.

For the systematic application of sewage to filters, especially contact beds, there are several devices on the market, most of which it is believed work pretty well so long as the filters are in good condition. So far as known there are no devices for treating filters which are clogged seriously, and probably there will not be. In other words, sewage filtration, while much benefited by "dosing devices," must also receive competent attendance and supervision if good results are to be regularly secured. Much progress in the last 10 years has been made in means for applying sewage to filters, but there is still much room for improvement, especially as regards "continuous intermittent filters."

Even in the case of intermittent sand filters it is worth noting that there are nearly as many designs for sewage application as there are plants. Most of them work well enough in warm weather, but during freezing weather this is hardly so, except perhaps in the case of very small beds.

Concerning Patents.

Ten years ago the engineer in designing a sewage purification plant had little or no occasion to consider the patent question. As available methods have been supplemented since that time by coarse-grained rapid filters and by various preparatory treatments, including the septic process, numerous patents have been issued in this country. Generally speaking, engineers have been disposed for the most part to disregard these patents until the validity of their claims was established by court decisions, especially as the patents were claimed by their owners to cover pretty nearly all designs except those for simple intermittent filtration or simple chemical precipitation. It is said that practically all "compound" types of treatment, involving more than one step, are claimed to be covered by patents.

What the merits or demerits may be of these various claims cannot be touched upon in this review, in advance of court decisions, other than to record the fact that the City of Plainfield, N. J. (which built septic tanks and contact beds in 1901), is defending a suit brought by the U. S. Sewage Purification Company for alleged infringement of their patent, No. 559 522, and also another suit brought by the Cameron Septic Tank Company for alleged infringe-

ment of their patent, No. 634 423. The City of Pawtucket, R. I., which at times has operated its settling basin as a septic tank preliminary to intermittent filtration (works built in 1893), is also defending a similar suit brought by the former company.

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SEWAGE DISPOSAL.

SEWAGE DISPOSAL IN FRANCE.

By M. Bechmann.*

Translated from the French by
George W. Fuller, M. Am. Soc. C. E.

In France during the last ten years marked progress has been made in the treatment of sewage, although this particular branch of municipal sanitation has not received all the attention which it deserves.

Purification by irrigation has certainly given some remarkable results; while mechanical, chemical and biological processes have only been the objects of isolated experiments or a few tentative installations.

Situation in 1894.

Ten years ago, only one city, Rheims (population about 100 000), was able to claim that it treated all its sewage effectively. In this instance the sewage was conducted, partly by gravity and partly by pumping, a short distance from the city limits to a purification field, where a thin layer of earth overlies fissured limestone. It was distributed under pressure in a piping system, suitably equipped with

* Ingénieur en Chef des Ponts et Chaussées, Chef du Service des Eaux et de l'Assainissement de Paris.

regulating valves, etc., to trenches, largely made by plowing. The rate of application was not more than 30 000 cu. m. per hectare per year (equal to about 3 200 000 U. S. gal. per acre annually, or an average daily quantity of about 9 000 gal. per acre). The sewage was not only purified in the porous soil, but at the same time served for the fertilization of an agricultural area conceded by the city to a company, and enlarged by the latter. This concession was made with the proviso that, to prevent all contamination, the sewage should not reach the watercourse which drains the region, the Vesle, until after its purification.

This was the first systematic application of the process advocated since 1864 by Mille and later by Alfred Durand-Claye for the City of Paris, and which since 1868 has been the object of notable investigations and results at Gennevilliers. Notwithstanding the favor with which the agriculturists of this region, after their first opposition, welcomed finally the use of sewage for their farms, which they have little by little extended to nearly 900 hectares (2 225 acres); notwithstanding the complete purification of the sewage thus treated and rendered not only inoffensive but so free from organic matter, ammonia and bacteria as to be fresh, limpid and practically potable; and notwithstanding the persistent efforts of the City of Paris and the support of the Board of Public Works, the passage of a law, by the Chamber of Deputies and the Senate, in 1889, to permit an extension of the system to the area at Achères, on the border of the Forest of Saint-Germain, was obtained with great difficulty. The works undertaken by virtue of this law, not having been completed, public opinion remained hostile, and circumstances were but slightly favorable to new methods.

Only a few isolated institutions, such as the asylum and prison at Nanterre, and the insane asylum at Ville-Evrard, under the Department of the Seine, had undertaken to treat their sewage by this process. At these places the sewage was applied to neighboring porous fields, which irrigation had transformed into kitchen gardens, the products of which were used in feeding the inmates. The unquestioned efficiency of this treatment, on account of its simplicity and its success from the standpoint of both sanitary and economical results, had not, however, been able to triumph over the instinctive prejudice of the people against sewage purification by irrigation.

The details of the manner in which this process accomplishes its results had been revealed only a short time before, thanks to the discoveries of Schloesing, Müntz and Winogradsky, and to the demonstration of the biological agencies which are operative in the surface layers of the soil. These biological actions are effected by certain kinds of bacteria, some of which bring about the decomposition of organic substances and others the nitrification of nitrogenous matters, thus, in brief, accomplishing by natural means the return of the wastes of vegetable and animal life to the mineral state.

Some smaller cities had also applied their sewage to neighboring fields; but, excepting perhaps Montélimar, they had not used the process in a systematic way to effect satisfactory purification, as they really applied the sewage to facilitate the agricultural side of the process without consideration of the sanitary point of view.

Chemical or mechanical processes had been employed on a large scale in only a single instance, namely, the plant, still incomplete, for the purification of the Espierre, a small stream which receives the sewage of the Cities of Roubaix, Tourcoing and Wattrelos (population 222 000), and which contaminates seriously the Escaut, which it joins near the Belgian frontier. The presence of a considerable quantity of greasy matters coming from wool-scouring establishments renders the problem of purification there particularly difficult. Lime employed at Grimonpont had not given satisfactory results. The tentative use of other chemicals, such as perchloride of iron (Gaillet), sulphates of iron and alumina (Houzeau), ferrous phosphate of soda (Boblique), and ferric sulphate (Buisine) had also been more or less ineffective.

Electrolysis for the decomposition of a dilute solution of alkaline chlorides, in order to make a liquid capable of effectively deodorizing and sterilizing sewage, had been proposed by M. Hermite and tried with but little success at Hâvre, Lorient, Brest (1893) and Nice (1894).

Purification by Irrigation Since 1894.

The extension of the irrigation works for the treatment of Paris sewage upon the area of Achères (800 hectares, or nearly 2 000 acres), undertaken under the law of July 10th, 1889, was com-

pleted in 1895. This, however, was only a step toward the final solution of the problem, since the new purification field, as in the case of that at Gennevilliers, is only able to receive the quantity authorized by law, which is 40 000 cu. m. per hectare per year, or 4 280 000 U. S. gal. per acre per year, equal to 11 800 U. S. gal. per acre daily on an average. This was only a fraction of the total sewage flow, and the greater portion still continued to discharge into the Seine. All these additions, however, were designed by the municipal service to be of such proportions that they could later be utilized satisfactorily with the further extensions to be undertaken in connection with the "purification of the Seine," which had for its ultimate object the treatment by irrigation of all the sewage of Paris. Since July 10th, 1894, a new law has been operative, which authorized the necessary extensions to the existing works and created the necessary funds for their construction. Work was undertaken immediately, and after an interval of five years after the passage of the last law, that is, since July 8th, 1899, the discharge of the great intercepting sewers of Paris into the Seine ceased.

Since the last date, supplementary works have been built, and others still remain to be undertaken. It can be said, nevertheless, that at the present time the objects sought have been attained, namely, the entire sewage of Paris, increased by a notable part of the sewage of its suburbs, is regularly applied to purification fields —the only exception being portions of the storm-water flow at times when the sewer overflows are in operation. All the ordinary flows, from 600 000 to 700 000 cu. m. (from 160 000 000 to 185 000 000 U. S. gal.) per 24 hours, are treated systematically on the irrigation fields.

In order to accomplish this result, it was necessary to overcome many technical difficulties in the design of the necessary works; to construct important pumping stations at Clichy (1 800 h. p.), at Colombes (6 000 h. p.), at Pierrelaye (1 200 h. p.); to cross the Seine three times and the Oise once by means of a metal bridge (Argenteuil), a submerged siphon (Herblay), and two tunnels constructed with the aid of compressed air (Clichy and Maurecourt); to create a vast network of reinforced concrete conduits (200 km., or 125 miles) from 0.10 to 1.10 m. (4 to 44 in.) in diameter, for the distribution of the sewage; to establish drains for the return of the

purified sewage to the Seine and the Oise; to prepare some 800 hectares (1 980 acres) of agricultural park lands at Achères, some 500 hectares (1 235 acres) of city land at Méry, and to acquire and put in a state of cultivation the properties at Fonceaux (200 hectares, or 495 acres), at Grésillons (100 hectares, or 247 acres), and at Picquenard (200 hectares, or 495 acres). The cost of these works was more than 45 000 000 francs (about $9 000 000).

Only a small part of the sewage from the collectors is able by gravity to reach one of the purification fields, that at Gennevilliers. The remainder flows to the receiving basin at the pumping station at Clichy, where the larger solid matters are retained and are removed by dredges discharging them into boats, by which they are taken away. The floating matters which are removed by screens are detached from the latter by moving rakes, and are conducted by mechanical conveyors to an apparatus where they are compressed so that they can be finally disposed of by burning. The sewage thus deprived of its coarser matters is lifted by centrifugal pumps, operated by steam or electricity, partly to the plain of Gennevilliers and partly to the pumping station at Colombes. At the latter station it is again raised, by means of piston pumps operated by steam, after a second sedimentation in a basin designed to retain all suspended matters having a specific gravity equal to that of water, and directed to the other purification fields except the higher portion of the plateau of Méry, which necessitates a third pumping by machines of the same type, located at the pumping station at Pierrelaye.

The annual expense of operation and maintenance reaches a sum of more than 3 400 000 francs (about $700 000).

The irrigated fields of Gennevilliers and Achères (those comprising the domains of Fonceaux and of Picquenard), as well as those at Carrières and Triel (those comprising the domain of Grésillons) are ancient alluvial deposits of the River Seine, composed of sand and gravel and having a thickness for filtration purposes of from 2 to 6 m. or more (from 6 to 20 ft). They are extremely porous, and in them the sewage is filtered very easily. Toward the sloping banks of the stream, however, there are modern deposits of muddy sand, which make it necessary at intervals to provide outlet pipes connected to the collecting drains. These serve to insure the proper

removal of the filtered sewage and to prevent the ground-water from reaching too high a level. The plateau of Méry (Pierrelaye) presents an entirely different appearance. It is about 55 m. (170 ft.) above the level of the Seine, and forms a filter of variable, but always considerable, thickness. This is composed in part of fine and medium sand, and in part of limestone covered with loam and a thin layer of soil. The purified sewage quickly caused the ground-water to rise, making it necessary to provide artificial outlets into the natural ravines leading down to the River Oise.

There are two methods by which these irrigation areas are conducted:

In part the city owns the lands (1 800 hectares, or 3 450 acres), renting them to farmers for an annual sum subject to the requirements of the purification process. That is, the tenants receive stipulated quantities of sewage at all times, night or day, and raise their crops, under permanent supervision and control.

By the second method the remaining 3 500 hectares (8 650 acres) belong to individuals, who receive the sewage when and as the interests of cultivation call for it, and without having to pay any ground rent.

Under this procedure an important increase in the value of lands has resulted, especially in those privately held, which have quintupled in value, at least, at Gennevilliers, where they are devoted to the cultivation of vegetables for the Paris market. The other areas have also gained in value each year, although the greater distance and lack of labor prevents farming on any but a large scale, the raising of cereals, potatoes, etc.

The operation of the irrigation system is controlled by commissions under the higher board of administration. They are compelled by law to present half-yearly reports and to see that the legal amount of sewage is distributed to the fields under cultivation without the formation of stagnant pools. These reports have never failed to show that directions have been carried out properly, and to attest to the satisfactory operation of the system. Proof of this one finds, among other ways, in the popular satisfaction which has succeeded the violent opposition first encountered; in the general eagerness of the agricultural population to take advantage of the fertilizing properties of the sewage to make their farms more

remunerative; in the increase of population in the localities adjoining the purification fields (that at Gennevilliers has tripled since the commencement of irrigation); and in the maintenance locally of normal sanitary conditions.

As to the degree of purification, without exception, results have been obtained which are certainly unequalled elsewhere, either by sewage irrigation or by any other process. The filtered sewage leaving the underdrains and entering the Seine or the Oise is invariably limpid and of admirable quality. Chemical and biological analyses show it to contain a proportion of organic matter and bacteria which (were it not for the richness in chlorine and nitrates, an unmistakable index to its origin) would permit it to be classed with potable waters of good quality. Table 14 gives a sample of the results regularly obtained at the laboratory of the Observatory of Montsouris with regard to the composition of the filtered sewage; and, for purposes of comparison, also some analyses of the raw sewage itself and of the ground-waters used as the domestic supply of the City of Paris.

The Department of the Seine has reached the same point of view with reference to the treatment of the sewage of the suburbs of Paris. Already a part of the sewage of the eastern district is conducted to a pumping station at Alfortville and pumped to a purification field established in an alluvial plain at Créteil. The thickness of the gravel deposits there are unfortunately less than those at Gennevilliers or Achères. Works have been undertaken to collect the sewage of the southwestern district and to convey it to the pumping station at Colombes, where it will be admitted and pumped with the Paris sewage to the purification fields of the city. For the northern district a similar project is now being investigated.

Various isolated establishments, notably the insane asylum at Vaucluse, the hospital at Brévannes, the institution at Villers-Cotterets, etc., have profited by the existence of more or less favorable fields in the neighborhood in order to purify their sewage by irrigation.

Some installations have been undertaken by various cities in other sections. Such projects have been taken up by Rouen, Lyons, St. Quentin, etc., and are being investigated for Bordeaux, Clermont-Ferrand, Dijon, etc.

TABLE 14.—Average Analytical Results for the Year 1901. Milligrams per Liter, or Parts per Million.

Constituents.	Raw sewage. (Clichy)	Filtered Sewage.				Ground-Waters.			
		Gresillons outlet. (Gennevilliers)	Herblay outlet. (Achères)	Liesse outlet. (Méry)	St. Blaise outlet. (Carrières)	Dhuis.	Vanne.	Avre.	Loing.
Mineral matter (lime)	152	307	259	182	263	107	117	84	113
Organic matter....	33.4	1.1	1.7	0.9	1.1	0.6	0.4	0.7	0.3
Chlorine.....	52	83	72	27	68	7	5	11	7
Nitrogen as: Nitrate....	0.8	28.2	19.1	19.7	21	2.1	2.2	2.4	3.7
Nitrogen as: Ammonia .	15.4	0	0.2	0	0	0	0	0	0
Nitrogen as: Organic...	6.7	0	0	0	0	0	0	0	0
Bacteria, per cubic centimeter	148 322 000	585	1 000	125	250	1 765	760	785	925

Biological Processes.

The appearance of biological processes will retard perhaps the full development of the projects mentioned previously by stimulating the study of others. But this competition will finally prove an advantage in the interests of hygiene by enlarging the scope of possible solutions of the problem of the purification of sewage, and permit the adoption of better works under some of the varying conditions of practice.

From the beginning it has appeared clear to the writer that engineers called upon to consider the treatment of city sewage have now at their command another method, based upon the systematic imitation of the processes set at work by Nature herself, and which, scientifically conducted, ought to show favorable results. Indeed, since March, 1898, the writer has followed with interest the experiments of Dibdin and of Cameron, the discussions which have occurred at the Sanitary Institute at London and the publications which have appeared on this subject before the two French societies particularly constituted to appreciate their true value, the Société

des Ingénieurs et Architects Sanitaires and the Société des Medicine Publique et d'Hygiène Professionnelle.

Between these new methods and the purification process applied to the Paris sewage, which also takes advantage of biological agencies, there are so many points of analogy that the writer felt sure they could be combined and associated to supplement each other. It was with this thought that he proposed promptly that the City of Paris investigate them. His highly qualified colleague, M. Launay, was delegated to inspect the installations already in operation in England and to receive at first hand, from the engineers who built and operated them, the results of their observation; and, finally, it was decided to conduct a series of experiments by these methods upon the sewage of Paris itself. The report of M. Launay was the first manifestation in France in a practical way of these biological methods. It was followed by the installation of a small experimental plant at Gennevilliers, which since then has permitted without interruption a trial on a modest scale of the biological treatment of the Parisian sewage. To this end were used the old basins where Mille made his first comparative tests of chemical purification and of irrigation in 1867-68.

These experiments, which have been conducted with contact beds of various materials and various combinations, with continuous filtration, and with septic tanks also, have not reached a point where final conclusions may be drawn. But certain provisional conclusions may be mentioned with reference to the treatment of Paris sewage, notably that it, having already undergone the effects of biological treatment to a partial extent, in the collecting and distributing sewers, has little to gain from the work of anaerobic bacteria in the septic tank; and that, freed from suspended matters to the degree effected by the basins at Clichy, it rapidly clogs the surface of primary beds, showing that it should be applied to such filters only after more thorough sedimentation. However, one is able without recourse to such preliminary process to treat the sewage successfully by the "continuous" method (on the old alluvial terraces which constitute the plains of Gennevilliers, Achères, Carrières and Triel) in quantities much larger than those authorized by the laws of 1889 and 1894, perhaps ten times as great, provided there is efficient drainage to assure the prompt removal of the effluent.

An experiment on a large scale according to this procedure was decided upon in 1902. Nine hectares (about 22 acres) of the municipal lands at Fonceaux were especially prepared for this experiment by the establishment of suitable underdrainage. In order to provide for the possibility of clogging, the surface was not brought under cultivation. The first results obtained are encouraging, and it is more than probable that there will be found in an extension of this method of operation an effective means of guarding against the difficulties encountered with sewage irrigation at certain seasons. This will especially be true, for example, when the needs of the crops call for a temporary suspension of, or a notable reduction in, irrigation, by having always ready some areas capable of receiving surplus sewage. Such areas would act as regulators, enabling the plant as a whole to be controlled as desired.

If in the treatment of the Paris sewage, so fortunately effected by the irrigation system, the new biological processes are able to appear only under the role of subsidiary treatments, they are doubtless able to render, and will render, signal service in some localities, where works have not yet been built, and particularly where the available land does not naturally lend itself to irrigation. Without doubt these processes will not be able to effect results as perfect as those realized by irrigation by the City of Paris. In the experiments made in France, as well as in those made in England, the reduction of organic matter is only partial, and the bacterial contents of the treated sewage are high. This does not prove, however, that there will not be further improvements in the technical aspects of the processes, and that the effluents leaving the underdrains of this system will not be clear non-putrescible and in a state to be returned without danger or annoyance to rivers the waters of which are not used for public water supplies. Indeed, the French hygienists presented to the International Congress of Hygiene at Brussels in September, 1903, conclusions to which they had arrived on the subject of biological treatment as follows:

"The biological purification of city sewage and of waste liquors from industrial establishments has received, by the introduction of these various artificial processes, a fortunate extension which is favorable to the sanitation of cities and of streams. These processes constitute a solution of many purification problems for cities and

for trade wastes which the engineers, hygienists, manufacturers and the municipalities will be able to take advantage of either when applied alone or when they are associated with other processes now already known. It is desirable, however, that the studies and investigations of their practical application be continued farther."

Dr. Calmette has become in France the advocate of the biological processes, in which he sees the true scientific solution of the problem of the purification of city sewage. It is his opinion that they may also be applied with success to trade wastes from isolated factories, provided they are suitably adjusted in each case according to the particular treatment to be effected. In some cases he would make use of certain precipitants, thus realizing in a manner a mixed chemical and bacterial treatment. At the Pasteur Institute, at Lille, of which he is the Director, he has undertaken some scientific experiments on a small scale, for the purpose of establishing and perfecting these methods in the interests of public hygiene and the industries.

As yet there are no notable installations in France, notwithstanding the efforts made by those interested commercially in the adoption of these processes and which have already become so numerous in England. In 1900, during the Exposition at Paris, Adams and Company, well-known in England, made an installation of their apparatus on the plains of Achères, under the direction of M. de la Ferond, Sanitary Engineer. Under the direction of M. Bernard Bezault, Architect, a test plant was established in 1902 near Paris, at the pumping station at Clichy, by the English company which exploits the septic tank. Projects have also been suggested for various other localities by M. Howatson. All these tentative endeavors have up to this time met with no practical results, but the time is coming, without doubt, when they will become more of a feature in new works.

Chemical and Mechanical Processes.

There is little to say regarding chemical and mechanical processes.

A new process has been devised and applied at Dorignies-les-Douai for the extraction of grease from wool scourings by M. Delattre. It consists in treating the waste liquors by dilute sul-

phuric acid, in applying steam to the precipitate and in passing it through a filter press. The grease is extracted either from the liquid part by decantation or from the solid part (cakes from the filter press) by benzine, and can be advantageously sold after purification. A contract has been signed and a trial recently made of the application of this process in somewhat simplified form at Grimonpont. The waste liquors, after having been freed from grease, will finally be subjected to a supplementary biological treatment.

M. Howatson has proposed for application at Rouen and Toulon, the processes of the International Water and Sewage Purification Company, Limited, based upon the use of a precipitant, ferrozone, composed of variable proportions of salts of alumina and iron, followed by rapid filtration through a bed of polarite. He has presented several projects, carefully worked out, none of which has been finally adopted.

The Dervaux apparatus which serves for the purification of hard waters by the use of milk of lime and a mechanical clarification, has been suggested for commerical application in the treatment of some trade wastes.

Recently a Wilson mechanical filter, which is cleaned periodically and automatically by reversing the flow of water, has been tried for the clarification of sewage, and has been proposed by M. Perreau, of the Department of the Seine, for trial on a large scale.

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DISCUSSION ON SEWAGE DISPOSAL.

By Messrs. J. L. Van Ornum, M. N. Baker, Dr. Samuel Rideal, Dr. Gilbert Fowler, Messrs. J. M. Coane, W. Thwaites, H. Ross Hooper, Andrew Rosewater, Allen Hazen, H. N. Ogden, E. J. Hanley, H. Birch Killon, Rudolph Hering, Robert Spurr Weston, M. O. Leighton, John W. Alvord, F. A. Barbour and George W. Fuller.

Prof. Van Ornum.

J. L. Van Ornum, M. Am. Soc. C. E., St. Louis, Mo.—While the septic tank requires very little attention if correctly designed, the speaker believes that some supervision is necessary, especially at the beginning, in order to determine the proper time of flow through it to secure the best results under the various conditions affecting each particular case. The small septic tank of Washington University, with a capacity of about 24 000 gal., receives no surface water, and so the house sewage from this separate system of sewers is rather strong; it is also quite fresh. This septic tank has been in operation for two years, and during the first year the purification was about 40%, mentioned in Mr. Fuller's paper as the ordinary percentage; however, efficient bacterial action was slow in establishing itself, as shown by the fact that a healthy scum did not form for many months. Since efficient bacterial action has been established, the removal of organic matter has been notably improved. A 20-hour period seems to give the best results in this case, the percentage of

Prof. Van Ornum. purification decreasing as the time in the septic tank is reduced below the time given.

Contrary to the statement in the paper concerning the usual odors, no odor is perceptible outside this septic tank, and but very little inside it.

Mr. Baker. M. N. Baker, Esq., New York City. (By letter.)—Mr. Fuller's able review of the present status of sewage disposal in the United States suggests three points for brief discussion: (1) The lead which intermittent filtration has over other methods of treatment, and particularly over the later and so-called bacterial filters or beds; (2) The slow progress, as indicated by the number of plants, made by chemical precipitation, and the rapid progress made by the septic tank in the past few years; (3) The great lack of data on certain phases of sewage treatment, and particularly the septic tank, contact bed and percolating filter, as compared with intermittent filtration.

Regarding the first point, it is gratifying to note that most American engineers and communities have concluded to await more definite results as to both the costs and results to be obtained from the so-called bacterial beds before giving up the well-tested system of intermittent filtration. This process, it may be added, has been carried to a much higher stage of development in the United States than in Great Britain, and in that respect it may be considered as a distinctly American contribution to sewage-treatment practice. It is to be feared that some of the American engineers who have been responsible for the introduction of so-called bacterial beds into the United States have not realized the differences between local conditions in Great Britain and America. Local conditions may justify or make necessary the use of contact beds and percolating filters composed of all sorts of more or less perishable material, in England, while calling for nothing of the sort in many sections of the United States. As Mr. Fuller remarks, however, the absence or scarcity of suitable material (sand) for intermittent filters in the South and great Central West makes the adoption of other methods than intermittent filtration in those parts of the country necessary. The same cause may operate in limited areas in the Northeast and in the Far West.

Chemical precipitation in America was first checked by intermittent filtration and latterly by the septic tank. Present indications are that it will continue to hold its own here for many years to come, and that plain sedimentation will not infrequently be preferred to septic tanks.

The lack of data on the practical working of septic tanks and so-called bacterial filters might well stimulate more of our cities and towns to keep the careful records of cost and of chemical and bacterial results, which have been such notable features of the operation

of a few works. The rapid processes of treatment involve expensive construction which has not yet been reduced to a well-known unit basis. The same may be said regarding operating expenses. The degree of purification effected is lower than that obtained by intermittent filtration, and the sludge problem is by no means eliminated by any of the newer processes yet established on a practical working basis. Mr. Baker.

While the foregoing remarks are believed to be true and worthy of careful consideration, it should be remembered that septic tanks, contact beds and percolating filters are being rapidly introduced into Great Britain, and, after allowing for the differences in conditions already noted, deserve serious consideration in America. Perhaps this consideration should be more serious and more general than it has yet been; assuredly it should be more scientific and have more relation to all the comparative details of cost and sanitary results.

Dr. Samuel Rideal, London, England. (By letter.)—Sewage disposal by dilution in salt water is, in the writer's opinion, not satisfactory, in the majority of cases, in the neighbourhood of oyster beds; and the evidence concerning it is perhaps more clearly defined in Great Britain than Mr. Fuller believes. Dr. Rideal.

The writer thinks that methods of partial sterilisation, possibly after septic tank treatment, so as to remove the pathogenic organisms, and arrest putrefactive changes, must be adopted in such places, in order to safeguard the oyster and other shell-fish industries.

Mr. Fuller, in dealing with sewage disposal by dilution in inland streams, clearly points out that the prevention of gross nuisances can be dealt with by dilution methods, but this does not remove infection. It is, however, generally more economical to purify from pathogenic organisms, such water as is required for drinking purposes, than to purify all sewage in this way.

Complete sterilisation of sewage effluents is useless, besides being costly; methods may be devised in which there will be a small quantity of active chemical, such as chlorine or ozone, after the removal of the greater portion of the organic matter, which will ensure the death of the common pathogenic organisms, together with many of the organisms which are conducive to putrefactive change, and thus ensure the safety of the stream into which such effluent discharges.

The possibility of a copper-sulphate treatment, foreshadowed by the United States Department of Agriculture, should also have consideration in this connection, as the writer has recently been able to confirm the statement, that very small quantities of this salt are capable of removing *B. coli* and *B. typhosus* from polluted waters. Such processes may revive methods of broad irrigation, or sewage

Dr. Rideal. farming after septic treatment, as, in this way, smell and danger of infection will be removed, together with the liability of choking the land, which obtains when crude sewage is dealt with.

Too much attention cannot be given to the protection of the surface of artificial filter beds, as the prevention of surface clogging is all-important for ensuring efficiency.

The writer is strongly in favour of intermittent continuous filters, worked by means of some sprinkling device; and uniformity of distribution is also a very important factor in diminishing the cost. It is often forgotten that the cost of distribution is only a small fraction of the total cost of the material of a bed, and that by attending to this factor the amount of material required for dealing efficiently with a given sewage may be reduced considerably.

The writer agrees with Mr. Fuller as to the uselessness of covering in septic tanks. He has found that a simple wind screen ensures quiescence on the surface of a septic tank, or, in other places, he has succeeded in obtaining a uniform scum by means of scum boards. Both these devices are far more economical than roofing in the tank.

Dr. Fowler. Dr. Gilbert Fowler, Manchester, England.* (By letter.)—The writer agrees generally with the statements contained in Mr. Fuller's paper, which seems to be an excellent summary of the present position of the sewage question. A few points, however, lend themselves to comment or amplification.

The statement on page 150 that "sewage putrefies more quickly in salt water than in fresh water" does not at first sight agree with some laboratory experiments made in Manchester, which appeared to indicate that salt had a distinctly retarding effect on septic action. The fact that nitrification has been shown to take place extremely slowly in sea water may, perhaps, reconcile the apparent contradiction.

The writer would like to emphasise the importance of obtaining more complete and accurate statistics of costs of construction and maintenance of sewage purification works, referred to on page 154. It would be well if some basis of comparison could be agreed upon, *e. g.*, the construction cost of filters per acre-yard or per meter-hectare, the quantity treated by these units in gallons or cubic meters, and the cost of treatment per million gallons or per cubic meter, and the percentage of purification obtained.

With reference to the further treatment of effluents from rapid filters, mentioned on page 159, it is now generally required by the sewer authorities in England, especially in the case of open-grained "percolating filters."

The question of washing or re-screening the material of contact

*Supt. and Chemist, Corporation Sewage Works.

beds, and, in certain cases, also of percolating filters deserves more careful attention. The writer's own view has always been that it is not as serious an operation as was at one time imagined. Recent experience at Burnley, England, has shown that material can be washed and put back for 1 shilling per cu. yd. The washed material is of much better quality than the original material, as everything liable to disintegrate has broken down during the working of the filter, and only the hardest portions remain after washing. Experience in Manchester with septic-tank effluent would indicate that "strainers," such as those referred to on page 186, entail too much cost in proportion to the work they do. If of an open-grain material they do not effectively strain a septic-tank effluent, if of a finer grain they need frequent and expensive cleaning. Undoubtedly something may be done to protect contact bed and continuous filters by keeping the level of the sludge in the septic tank below the point where it tends to pass away with the effluent, and by a judicious use of fine material on the surface of the filters. But a very important point, that is often forgotten by engineers, is that it is not only the suspended matter originally present in the sewage or effluent that has to be considered, but still more the insoluble matters, organic and inorganic, which are thrown out from the liquid after oxidation. In the case of sewage containing iron salts in solution, hydrated oxide of iron is also thrown out in this way. In order to avoid trouble and expense with elaborate straining arrangements, it appears better to look forward at once to a periodical washing of the filter material, and concentrate all costs to this one operation. Dr. Fowler.

In regard to the question of storm flows, mentioned on page 161, the writer agrees with the opinion given by the Chief Inspector to the Mersey and Irwell Joint Committee in a recent report, *viz.*, that all storm water should, if possible, be passed through tanks before it is admitted to the streams. Otherwise deposits may be formed by one storm, following a period of dry weather, which may neutralize much of the efforts given to purify the dry-weather flow.

Recent experience in Manchester has shown that with a fairly large reserve area of filter beds there is no great difficulty in purifying large volumes of storm water after it has passed through tanks. In England, six times the dry-weather flow has to be treated by some form of filtration. This figure is based, as a rule, on a reasonable dry-weather flow, *e. g.*, 40 gal. per head. There would appear to be very good reasons for restricting water waste in America, as undoubtedly a large flow per head does increase the difficulty and expense of operating works, though not of course in direct proportion, as the filters can, within limits, be worked at a higher rate with dilute than with strong sewage.

Dr. Fowler. The writer fully agrees with the importance of correct "biological construction," mentioned on page 172. Whenever possible, septic tanks and filters should be started in the early summer.

Interesting cases of the over-septic treatment of sewage, mentioned on page 183, have been met with in England, notably in the case of the installation at the new Christ's Hospital School at Horsham. Here the difficulty arose through the tank having to be shut down during the holidays, and it was remedied by allowing a certain amount of clear water from the water mains to run through the tank during the vacation.

While, no doubt, it is often possible, by single contact beds, operated at a low rate, to get very fairly satisfactory results, yet the writer cannot agree with Mr. Fuller in his apparent assumption that these results are as good as can be obtained by double contact. For a given size of material, a greater percentage of purification will always be obtained by double contact than by single contact of the same total area, though, no doubt, local conditions may necessitate the latter alternative.

The whole question of sewage disposal turns upon the careful consideration of local conditions and the cost entailed by the various methods of purification available.

Mr. Coane. J. M. Coane, Esq., Melbourne, Victoria. (By letter.)—Engineers of this State of Victoria, Australia, on reading Mr. Fuller's admirable paper will, no doubt, be struck by the statement in his opening paragraph, that the vast majority of American communities dispose of their sewage in the way stated, and, when they read that 20 400 000 people discharge their raw sewage into inland streams and lakes, while only 1 100 000 have undertaken purification works, they will certainly be surprised that such a state of things should exist in the United States. Unfortunately we, in Victoria, are ourselves none too forward in this respect. Our capital, Melbourne, with a population of about 450 000, is now well on with its sewerage works, in which the disposal is effected by sewage farming and intermittent downward filtration. These works are about 30 miles from the city, the effluent flowing into Corio Bay, an arm of Port Phillip. At a small country town, Shepparton, on the Goulburn River, a population of about 3 000 has installed a septic plant so that its sewage may not flow untreated into the river, and the Victorian Railway Department, at a few railway stations where convenient outfalls could not be had, has adopted septic tanks and bacterial filters with excellent results. With these exceptions, practically all our sewage is untreated. Bendigo, Ballarat and Geelong, with roughly 40 000 inhabitants each, have absolutely no sewerage systems. The two former are mining centers, and discharge their foul waters untreated into small creeks with no permanent flow, and the con-

ditions are bad. Geelong is at the head of Corio Bay, on high ground between that bay and the Barwon River which discharges into Bass Straits outside Port Phillip. The sewage from this town is allowed to flow also untreated into the bay (practically tideless) and the river, and the conditions here again are very bad. Mr Coane.

Most of our inland towns are on creeks or rivers with very small, or even no summer discharges, and the general practice is to carry the sewage to the stream a little below the town, without any previous treatment.

A few small towns are on lakes, which generally receive the sewage, or such of it as does not soak into the ground or evaporate before it reaches them, and, in a few other cases, small towns are built on arid plains of tertiary formation and many miles from a lake, a creek, or even a considerable depression. In the last-mentioned cases, the foul waters are carried away, in rather imperfect drains, a short distance from the town, and allowed to evaporate or soak away, pits being sometimes excavated to help the latter process; the water supplies in such cases are usually from irrigation channels. In addition to the above, we have two or three coast towns that can carry their wastes more or less directly to the open sea to be diluted in large volumes of salt water. None of the towns in this State, except Melbourne, has a water-closet system, though most of them have fairly copious, if sometimes rather impure, water supplies, and the excreta are disposed of by the pan or pail system. It need scarcely be said that at certain seasons typhoid fever is far too prevalent.

The collection of sewage in towns in nearly level country may be referred to in connection with disposal, as, in many cases, bacteriolysis is largely effected in the open drains which are very common here. For instance, in the case of Shepparton, where a bacterial plant was installed a couple of years ago by the writer's firm, there are long lines of open brick drains, laid down many years ago, with very slight falls leading to pipe sewers discharging to the detritus tank. In these brick drains, especially during the hot summer weather, the sewage soon putrefies, and we have found that by passing it through a timber-covered detritus tank, 9 ft. in diameter, and then to a filter of finely broken stone, 4 ft. deep, with battered open-rubble retaining walls, a fairly good effluent is obtained. Owing to want of funds, the building of the septic tank had to be postponed, and we feared that the sewage would not be sufficiently broken down before reaching the filter, but the action in the open drains has been such that a considerable scum has been formed in the detritus tank, and liquefaction of solids and evolution of gases have gone on satisfactorily. The sludge has to be removed from the detritus tank about once in six months, but it

Mr. Coane. has been found to contain a good deal of sand. It must be mentioned, however, that there are several gully pits in the system, which intercept a good deal of the solid matter before it reaches the pipe drains. The cost of scavenging is high, as the open drains are not self-cleansing, while the sewers require flushing to keep them free. No very objectionable odors are found at the bacterial plant; indeed, there is a sort of public camp on a Crown Reserve only a few yards from the tank and filter. The only trade waste that gave trouble was that from a rather extensive butter factory; this, however, has been dealt with under our direction by the use of copperas and lime, in the proportions of 1:4. It is found that the water from butter factories is particularly foul, and that it is advisable to treat it chemically as well as to remove the grease before admitting it to the sewers.

Contact filters on the fill-and-draw principle were tried by the Railway Department of this State, but have been abandoned in favor of sprinkling filters. In Victoria, too, we find that a good many people still believe that sewage can be purified by septic treatment alone, and we have seen installations at private houses that were very much worse than useless, causing most offensive odors and being generally disgusting.

It is thought that the people here are waking up to the necessity for better sanitary arrangements, and we have designed a scheme, not yet carried out, for the small but progressive town of Kyabram on the Northern Plain of Victoria, where we propose to collect by Shone ejectors, and to dispose of the effluent, after bacterial purification, partly by the irrigation of market gardens and partly by soakage into a porous substratum found in the district.

In the adjoining State of New South Wales, a good deal more has been done in the direction of correct sewage disposal than in Victoria, and some quite considerable plants have been installed. There the septic tanks are commonly uncovered, and sprinkling filters are, we believe, preferred to contact beds.

We have not heard of any sand filters being used for sewage, but no doubt they would work well here, as in no case would there be any difficulty, worth speaking of, from frost.

Mr. Thwaites. W. THWAITES, M. INST. C. E., Melbourne, Victoria. (By letter.)* —The method of sewage disposal adopted in connection with the Melbourne sewerage system is that of irrigation on properly prepared blocks of land.

The population of the Metropolitan Area, on December 31st, 1903, was 501 460, occupying 110 240 tenements extending over 91 118 acres.

Table 15 shows the densest municipalities:

* Engr. in Chief, Melbourne and Metropolitan Board of Works.

TABLE 15.

Mr. Thwaites.

Municipality.	Acres.	Population	Population, per acre.	Municipality.	Acres.	Population	Population, per acre.
					8 688	201 830	
Fitzroy	923	31 970	34	Melbourne	6 005	67 110	11
North Melbourne	565	17 010	31	Flemington	1 088	11 000	10
Collingwood	1 139	34 050	30	St. Kilda	2 046	20 550	10
Richmond	1 430	38 000	27	Brunswick	2 722	23 650	9
Prahran	2 320	41 000	18	Hawthorn	2 400	22 080	9
South Melbourne	2 311	39 800	17				
	8 688	201 830	23		22 949	346 220	15
Footscray	2 577	17 300	7	Northcote	2 850	10 030	4
Williamstown	2 775	13 750	5	Malvern	4 000	11 930	3
Essendon	4 000	18 200	5	Caulfield	6 080	10 100	2
Port Melbourne	2 366	12 260	5	Boroondara	8 320	9 180	1
Brighton	3 288	10 160	3	Coburg	4 800	7 500	2
				Preston	8 800	3 800	½

The population of Melbourne is very scattered, no portion having a greater residential population than 40 or 50 persons per acre.

Of the total number of tenements in the Metropolitan Area, 73 000 have the sewerage reticulation already provided for them, and of these 67 000 are connected with sewers providing for 305 000 people.

All sewage is collected by two main lines of sewers and concentrated at one pumping station at Spottiswoode, a portion of the Town of Williamstown. At the present time, the longest distance that sewage has to travel from the most distant sewer now constructed to the pumping station is 10½ miles.

At the pumping station, the sewage is pumped through two wrought-iron rising mains, 4 and 6 ft. in diameter, respectively, for a distance of 2¾ miles, and a total height of 109½ ft. to the head of the outfall sewer.

The outfall sewer is 15¾ miles long and 11 ft. in diameter, with a fall of 2 ft. to the mile; only about one-third of the length has been completely covered, the remaining two-thirds, in shallow ground, is open, being formed by constructing only the lower half of the circular sewer.

The maximum distance that sewage has to travel now is 10 miles 40 chains to the pumping station, and 30 miles to the farm.

The center of the farm is about 25 miles in a direct line south-west of the General Post Office.

The following details are given of the Melbourne climate for comparison with other cities. The city was founded in 1837. Meteorological records were commenced in 1840.

Mr. Thwaites.

Climate.—Annual rainfall: Average, 25.55 in.; minimum, 15.61 in.; maximum, 44.25 in. Seasonal average rainfall: Summer, 5.88 in.; autumn, 6.47 in.; winter, 5.77 in.; spring, 7.37 in. Average number of days rain in the year is 133, varying from 102 to 154 days per annum. Annual humidity: Average, 71%; minimum, 67%; maximum, 74 per cent. Monthly humidity: Average varies from 64% in December and January to 80% in June and July. The average annual temperature is 57.5 degrees.

The absolute maximum in the shade is 111.2°, and the absolute minimum ever recorded, 27 degrees. The highest recorded solar registration was 178.5° on January 14th, 1862, and the lowest terrestrial radiation, 20.4° on June 17th, 1895. The mean winter temperature is 49.2°, and the mean summer, 65.3°, giving a mean range of 16.1 degrees. The mean daily range in winter is 14.1°, and in summer, 21.5 degrees.

Water Supply.—During the period, 1891 to 1903, the annual average daily supply varied from 23 486 000 in 1892 to 29 447 000 in 1901.

The daily supply per head has averaged 57 gal. during the last 10 years, and during the last 4 years, 58 gal. The daily supply per tenement is 268 gal.

TABLE 16.—Average Daily Supply in British Gallons.

Month.	Minimum.	Average.	Maximum.
January	28 306 000	33 093 000	35 822 000
February	28 499 000	34 667 000	41 630 000
March	25 009 000	30 186 000	33 611 000
April	21 281 000	25 211 000	28 563 000
May	19 413 000	22 521 000	27 147 000
June	17 036 000	21 287 000	25 690 000
July	17 273 000	21 321 000	34 349 000
August	18 119 000	22 128 000	26 581 000
September	19 534 000	22 665 000	27 136 000
October	21 836 000	25 067 000	29 047 000
November	25 178 000	29 339 000	34 957 000
December	28 575 000	33 102 000	38 276 000

Sewage Pumped.—During 1903, 5 389 488 000 gal. of sewage were pumped, averaging 449 124 000 gal. per month, from an average number of 55 838 tenements connected, giving 264 gal. per day per tenement; the cost of raising 1 000 gal. of sewage 100 ft. high was 0.375 or 0.44 pence per 1 000 gal. pumped the full height for coal, wages, and maintenance of pumping plant. The average cost of coal was 17s. 6d. per ton (2 240 lb.).

The sewage passes through wire strainers before entering the pumping station, and, during 1903, 9 581 barrowsful of screened ma-

terial, equal to 709 cu. yd. or 641 tons, were taken from the cages and dried by steam in Johnson's driers, reducing the stuff to 263 cu. yd. or 100 tons of innocuous fiber, which has no offensive smell. Mr. Thwaites.

The cisterns used in the water closets discharge 3 gal. at every flush.

The separate system has been adopted, only rainfall from specially polluted areas, such as cab stands, stables, dairies, etc., being taken, and in very few cases has rainfall water been allowed to be taken into the sewers. The result is that as very little road detritus has to be dealt with in the system, the cost of maintenance is comparatively low.

On August 4th, 1904, 65 383 tenements were completely connected and 1 160 in progress. The fittings, then attached, consisted of 72 091 water closets, 47 037 baths, 35 095 sinks, 25 881 sets of washing troughs, 13 414 lavatories, 5 772 stables, 5 165 urinals, 1 225 cellars, 908 paved yards, 742 slop hoppers, 127 latrines and 82 dairies.

Sewage Analysis.—The analyses in Table 17 give an idea of the character of the sewage:

TABLE 17.

Insoluble Residue.	Grains per gallon.		
Organic	18.9	16.4	10.6
Inorganic	11.0	11.6	1.2
Total	29.9	28.0	11.8

Soluble Residue.	Grains per gallon.		
Fixed Saline	248	220	262
Organic Volatile	15	23	47
	263	243	309
Lime as CaO	16	15	13.2
Magnesia as MgO	20.1	14.5	19.2
Sulph. Acid as SO_3	7.8	6.2	26.9

Bacteriological Results.—The crude sewage carries from 2 000 000 to 5 000 000 micro-organisms per cu. cm.

Sewage Farm.—The farm contains 8 847 acres of land at £17 10s. per acre and cost £155 037. The sewage is delivered on the farm

Mr. Thwaites. at about the middle of its northern boundary. The area is now subdivided as follows:

	Acres.
Area prepared for intense cultivation	1 812
" " " broad irrigation	996
" " as settling ponds in winter	634
Land under preparation	137
Area leased as ordinary agricultural land not irrigated	4 569
Private roads and channels	281
Township sites	37
Plantations and reserves	381
Total	8 847

Up to December 31st, 1903, the following works have been carried out:

Steam ploughed for irrigation	2 446	acres
" " " plantations	381	"
Mole-drained by steam plant	1 067	"
Under-drained with pipes	481	"
Main carriers: Cement concrete	565	chains
" " Embankments	591	"
Subsidiary carriers: Embankment	1 599	"
" " Cast-iron flumes	1 237	"
" " Cement-concrete flumes	46	"
Drains: Main	1 523	"
" Subsidiary	4 321	"
" Pipe drains	2 161	"
" Agricultural pipes	2 097	"
Trees planted	137 830	
Roads formed	1 934	chains
Fencing	179	miles
Water-supply pipes, 6 in. diameter	185	chains
" " " 4 in. "	768	"
" " " 3 in. "	7	"
" " " 2 in. "	509½	"
" " " 1½ in. "	53	"
" " " 1 in. "	154	"
Houses erected	46	
Wire netting	737	chains
Tramways	7 000	lin. ft.

The land bought for the sewage farm forms part of the delta of the Werribee River, which runs into Port Phillip Bay about 24 miles southwest of Melbourne.

The chemical analyses of the soil, prior to purchase, gave the results, contained in Table 18. Mr. Thwaites.

TABLE 18.—Chemical Analyses of Soil.

	Parts per 100 000.				
	Nitrogen.	Phosphoric Acid.	Potash.	Lime.	Chlorine.
Upper Layer, 0 ft. to 2 ft. 1 in.	77	105	340	364	42
Second Layer, 2 ft. 1 in. to 4 ft. 7 in.	56	132	330	868	79
Third Layer, 4 ft. 7 in. to 7 ft. 6 in.	48	85	194	530	129
Average	59	106	280	597	88

Compared With Other Victorian Soils.

Rich Soils:					
Bungaree, volcanic	286	375	380	890	....
Bellarine, volcanic	383	294	271	816	9
Warnambool, volcanic	469	160	562	3460	4
Mitchell River, alluvial	350	149	203	492	20
Medium Soil:					
Goulburn Valley	130	102	298	317	11
Poor Soil:					
Panton Hills	87	30	135	63	7

The rich soils of Victoria require very little manuring. The second-class lands of the Goulburn Valley require manuring, though they can be profitably cultivated without manure. The poor soils represented by Panton Hills require manuring.

The sewage farm land may be classed as a second-class land deficient in nitrogen, which, however, the sewage is able to supply.

All the areas laid out for intense cultivation have been broken up by the steam ploughing plant of Fowler and Companies of Leeds, consisting of:

Two compound ploughing engines, 20 nominal h. p.
Five-furrow Kent plough, taking furrows, 16 in. deep.
"Oliver plough," one furrow, 24 in. wide and 30 in. deep.
Farming cultivator with ridging bodies.
Mole plough for forming mole drains 3 ft. 6 in. below the surface.
Light cultivator.
Ditching machine.
Harrows and Crosskill rollers with travelling frame.

Mr. Thwaites. Combined drilling, sowing, manuring, rolling and harrowing machine.

The experience gained since 1897, when the first sewage was delivered on the farm, points to the following principles, which must be adhered to, to bring about the most successful results:

First.—Thorough drainage, so that all superfluous moisture must pass downward through the land and not be allowed to be evaporated; no drain should be less than 3 ft. below the surface, but 5 ft. is better.

Second.—All the land should be thoroughly broken up to a depth of 2 ft.; this is easily accomplished with the Oliver plough.

Third.—The intensely cultivated blocks must be graded into level terraces; the size of each terrace depends upon the fall on the block. After preparation and watering, all hollow places must be brought up level so as to prevent ponding.

The Werribee Metropolitan Farm has been laid out on these principles, with the result that 12 000 000 gal. of sewage from 300 000 people are dealt with on:

1 812	acres	by	intense cultivation.
996	"	"	broad irrigation.
664	"	"	settling pits, water sewage.
3 472	acres.		
137	"		under preparation.
3 609	"		available without interfering with present leases.

In full work and complete preparation, this area should be able to deal with the population now being provided for, *viz.*, 500 000.

The blocks are sown with lucerne (alfalfa) and prairie grass; the former providing good summer feed, and the latter, good winter and autumn returns.

The sewage is brought into the area by the main outfall sewer at about the central portion of its northern boundary; the sewer then will divide into two branches, but at present only the eastern branch is constructed. The main carriers run north and south through the farm at a distance of half a mile from one another. Each carrier supplies sewage to the blocks for a quarter of a mile on each side. At every 10 chains, branch carriers are constructed to supply the blocks which cover 20 acres gross area, the available area for grass being about 18 acres, after the land broken up by channels, ditches and roads is deducted.

At the lower side of each block, there is an open drain from 3 to 5 ft. deep, leading into the main drain. The main drains are

½ mile apart, parallel to and alternate with the carriers. The effluent water from each sewered block is picked up by the side drains and then led to Port Phillip Bay through the main drains. Mr. Thwaites.

The blocks themselves are drained with mole drains or agricultural pipes wherever necessary. Six and nine-inch underground pipe drains are also provided in two or three main lines in each block.

A sewage farm was chosen for Melbourne, because the natural outlet is into the bay, and all along the eastern shore there is a continuous and growing littoral population, while, on the western side, any sewage thrown into the bay would have a tendency to drift back into Hobson's Bay, which would have immediately caused trouble. An ocean outfall was beyond consideration on account of the expense.

Land suitable for irrigation was available away from any existing population with an annual rainfall of only 20 in. and within a reasonable distance of a good market. The value of the land was not prohibitive.

Taking all things into consideration, James Mansergh, Past-President of the Institution of Civil Engineers, London, after considering the various methods of disposal possible, recommended irrigation in preference to other methods of disposal. His advice was adopted, but instead of having two farms on opposite sides of the bay, all the sewage has been concentrated at one pumping station and on one farm, thus saving an annual cost in supervision and working expenses.

In summer, there is no difficulty in dealing with all the sewage sent on the farm, but in winter, in wet weather, the sewage is more than the land can deal with readily. To provide for this, about 700 acres of low-lying salt swamps near the seashore have been broken up and prepared as settling pits.

The surface is only from 2 to 3 ft. above high-water mark, the rise and fall of the tide being about 2 ft. 6 in. to 3 ft. 0 in., so that it was difficult to drain this area properly directly into the sea.

The outlet drains into the bay have been provided with tide gates which are open while the tide is falling and closed when it is rising. The result has been that these useless salt swamps have been used as natural filters in winter for purification of the sewage by sedimentation and percolation. The altogether useless salt marshes are being fertilized with sewage, and the surplus salt washed out of the ground. During the summer, the blocks are scarified and sown with rape, which grows prolifically and affords excellent fodder. Some of the older blocks are becoming so much improved that they will soon be ready to grow excellent fodder grasses.

Mr. Thwaites. Bacteriological examinations of the effluents into Port Phillip Bay have given the following results:

July	8th, 1901,	purification,	96.74 to 98.87%
September	27th, 1901,	"	93.5%
August	29th, 1902,	"	95%
December	2d, 1903,	"	99.7%
June	23d, 1904,	"	97%

These results are due to the fact that these prepared blocks are not unduly dosed with sewage, and, as only about one-quarter of the available area is at present under intense cultivation, there is plenty of room for expansion.

The land not required for intense irrigation is let out to tenant farmers for ordinary cultivation, for periods of 3 to 5 years, but without irrigation. The rents received from these farmers have paid for the actual interest on cost of purchase of the land so occupied.

The Board, up to the present, has found that the buying and selling of sheep and cattle are the most satisfactory methods of dealing with the crops grown. Beyond this, considerable sums are obtained from grazing cattle and horses.

Tables 19 and 20 indicate the returns received from sheep transactions since November 4th, 1899:

TABLE 19.—Sheep Sales and Other Returns.

Year.	Sheep.	Amount.	Miscellaneous.	Selling Price.	Total.
		£ s. d.	£ s. d.	s. d.	£ s. d.
1899–1900....	6 677	5 295 13 8	.....	15 10.34	5 295 13 8
1900–1901....	16 291	13 454 8 9	9 19 1	16 3.81	13 464 7 10
1901–1902....	23 976	19 697 13 4	231 5 4	16 5.47	19 928 18 8
1902–1903....	37 498	33 704 1 0	364 4 10	17 10.733	34 068 5 10
	84 442	£72 151 16 9	£605 9 3		£72 757 6 0

Deaths	1 035
Balance in hand	13 241
Total	98 718

Thus up to June 30th, 1903, a profit of £13 059 had been made besides the stock in hand, *viz.*, 13 241 sheep. If these sheep be valued at 12 shillings, they were worth £7 945, giving a total return of £21 004 on £59 698 or 35 shillings per cent.

TABLE 20.—SHEEP PURCHASES AND EXPENSES. Mr. Thwaites.

Year.	Sheep.	Amount.	Miscellaneous.	Cost.	Total.
		£ s. d.	£ s. d.	s. d.	£ s. d.
1899-1900.....	11 230	6 819 18 9	321 16 10	12 8.62	7 141 15 7
1900-1901.....	16 303	10 078 0 10	867 9 7	13 3.27	10 945 10 5
1901-1902.....	28 459	15 434 11 6	1 268 0 2	11 11.29	16 702 11 8
1902-1903.....	42 714	22 936 2 3	1 972 6 1	11 8.48	24 908 8 4
	98 706	£55 268 13 4	£4 429 12 8		£59 698 6 0
Bred on farm.	12	.....	.....	.....	.....
Total.....	98 718			Profit.....	13 059 0 0
					£72 757 6 0

The following were the average profits for sheep during the periods:

1899-1900, 3s. 1.72d. per head, on..... 6 677 sheep.
1900-1901, 3s. 0.54d. " " " ..... 16 291 "
1901-1902, 4s. 6.18d. " " " ..... 23 976 "
1902-1903, 6s. 2.25d. " " " ..... 37 498 "

The relative profits for sheep each year were:

1899-1900. Sale of 6 677 Sheep @ 15s. 10.34d..... £5 295 13 8
Value of 4 553 " " 15s. 10.34d..... £3 610 18 2
£8 906 11 10
Purchase and expenses on 11 230 sheep @ 12s. 8.62d., 7 141 15 7
Profit..... £1 764 16 3

1900-01. Sale of.....16 291 sheep, wool, etc., @ 16s. 3.81d., £13 464 7 10
Deaths, 212 "
Value of 4 353 " @ 16s. 3.81d., 3 551 10 1

4 553 plus 16 303 = ... 20 856 " 17 015 17 11
Purchase and expenses on 16 303 " @ 13s. 3.27d., 10 945 10 5 £ 6 070 7 6
Less amount on..... 4 553 " brought forward..... 3 610 18 2
Profit..... £ 2 459 9 4

1901-02. Sale of.....23 976 sheep, wool, etc., @ 16s. 5.47d..£19 928 18 8
Deaths, 244 "
Value of 8 592 " @ 16s. 5.47d., £ 7 069 8 6

4 353 plus 28 459 = ...32 812 " £26 998 7 2
Purchase and expenses on 28 459 " @ 11s. 11.29d , 16 702 11 8 £10 295 15 6
Less amount on..... 4 353 " brought forward..... 3 551 10 1
Profit..... £ 6 744 5 5

1902-03. Sale of.....37 498 sheep, wool, etc., @ 17s. 10.733d.,£34 068 5 10
Deaths, 579 "
Value of 13 241 " @ 17s. 733d..£11 847 0 0

8 592 plus 12 births plus 42 714..... = 51 318 " £45 915 5 10

Purchase and expenses on 42 714 " @ 11s. 8.48d.,£24 908 8 3 £21 006 17 7
Less amount on..... 8 592 " brought forward..... 7 069 8 6
Profit..... £13 937 9 1

Mr. Thwaites. On the basis of the sheep on the farm being worth the average value of those sold during the previous financial year, the relative profits of each year have been:

1899-1900	£1 764	16	3
1900-1901	2 459	9	4
1901-1902	6 744	5	5
1902-1903	13 937	9	1
	£24 906	0	1

This gives a total profit of £24 900, the profits from the balance sheets give £21 000, calculating the value of the sheep on the farm at 12 shillings, but the average selling price for the year was 17s. 10¾d., or about 5s. 10¾d. more.

Table 21 shows the revenue from the farm on the above basis of calculating sheep returns, and Table 22 gives the working expenses and net revenue.

TABLE 21.—Revenue from the Farm.

Year.	Rents.	Grazing.	Miscellaneous.	Sheep.	Cattle.	Total.
	£ s. d	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
1892-93	297 0 0	.....	.....	.....	.....	297 0 0
1893-94	1 562 11 6	66 8 0	15 0 0	.....	.....	1 643 19 6
1894-95	2 328 6 1	10 2 0	94 0 0	.....	.....	2 432 8 1
1895-96	4 061 3 2	60 15 0	31 0 0	.....	.....	4 152 18 2
1896-97	4 172 16 6	145 0 7	86 2 0	.....	.....	4 403 19 1
1897-98	5 102 18 1	200 7 10	14 16 8	.....	.....	5 318 2 7
1898-99	5 395 2 8	372 8 6	48 8 1	.....	.....	5 815 19 3
1899-00	4 516 0 8	237 5 0	347 14 0	1 764 16 3	.....	6 865 15 11
1900-01	4 528 16 4	350 11 3	190 2 2	2 459 9 4	.....	7 528 19 1
1901-02	4 422 17 3	836 13 3	16 15 7	6 744 5 5	.....	12 020 11 6
1902-03	4 903 12 10	1 604 4 6	16 3 0	13 937 9 1	690 2 7	21 151 12 0

TABLE 22.—Working Expenses and Net Revenue.

Year.	Revenue	Working expenses.	Profit.
	£ s. d.	£ s. d.	£ s. d.
1899-1900	6 865 15 11	3 027 18 0	3 837 17 11
1900-1901	7 528 19 1	3 101 10 3	4 427 8 10
1901-1902	12 020 11 6	3 639 6 6	8 381 5 0
1902-1903	21 151 12 0	3 494 5 2	17 657 6 10

Mr. Thwaites.

TOTAL FINANCIAL WORKING OF FARM.

1899-1900.	Farm purchases,	£155 037, interest at 4%,	£13 895
	Farm preparation,	192 337, net revenue,	3 838
		£347 374, debit balance,	£10,057

The actual cost for 1899-1900 was £10 057, equal to a rate of 1.29 pence in the pound on the annual value, £1 864 181, of sewered properties gazetted on June 30th 1900.

1900-1901.	Farm purchases,	£155 037, interest at 4%,	£14 641
	Farm preparation,	210 982, net revenue,	4 427
		£366 019, debit balance,	£10 214

The actual cost for 1900-01 was £10 214, equal to a rate of 1.16 pence in the pound on the annual value, £2 120 608, of the property gazetted on June 30th, 1901.

1901-1902.	Farm purchase,	£155 037, interest at 4%,	£15 192
	Farm preparation,	224 751, net revenue,	8 381
		£379 788, debit balance,	£6 811

The actual cost for 1901-02 was £6 811, equal to a rate of 0.63 pence in the pound on the annual value, £2 591 894, of the property gazetted on June 30th, 1902.

1902-1903.	Farm purchase,	£155 037, interest at 4%,	£15 700
	Farm preparation,	237 473, net revenue,	17 657
		£392 510, net profit,	£1 957

There was thus a net profit on the total farm working for 1902-03 of £1 957.

The Board's operations in the Werribee District have rendered the railway traffic far more profitable than it was, due to the great incentive to local farming brought about by the results achieved by the Board and its tenants.

The revenue of the Werribee Railway Station has been very much increased, as shown in Table 23.

TABLE 23.—REVENUE OF WERRIBEE RAILWAY STATION.

Year.	Station Returns.	Year.	Station Returns.
1890-91	£2 970	1897-98	£8 765
1891-92	4 400	1898-99	6 518
1892-93	8 157	1899-00	8 933
1893-94	3 039	1900-01	11 674
1894-95	3 708	1901-02	10 016
1895-96	5 312	1902-03	12 831
1896-97	9 354		

Mr. Thwaites. The traffic of the Station, since 1895-96, is given in Table 24.

TABLE 24.—Traffic of Werribee Railway Station since 1895-96.

Year.	Outward.		Parcels.		Goods, Outward.		Live Stock, Inward Revenue.				Total Revenue.
	Passengers.	Revenue.	Outward.	Inward.	Tons.	Revenue.	Tons.	Revenue	Outward.	Inward.	
		£	£	£		£		£	£	£	£
1895–96.....	24 894	1 328	241	275	7 196	1 175	9 198	1 811	21	461	5 312
1896–97.....	29 606	1 662	215	266	23 287	4 182	8 430	2 136	31	862	9 354
1897–98.....	28 632	1 620	206	281	22 822	4 208	7 370	1 874	56	520	8 765
1898–99.....	24 642	1 404	213	264	12 944	2 389	5 788	1 428	39	791	6 518
1899–00.....	29 588	1 652	223	337	26 035	4 278	6 855	1 711	47	684	8 933
1900–01.....	37 229	2 112	242	339	41 122	6 204	8 208	1 815	63	899	11 674
1901–02.....	33 010	1 951	267	397	26 764	4 746	8 936	2 195	54	496	10 106
1902–03.....	37 014	2 005	296	373	30 321	6 168	11 336	3 312	92	584	12 831

The revenue of Werribee Station in 1890-91, before the Board's works started was £2 970. It increased during the construction of the outfall sewer in 1891-92 and 1892-93 to £8 157, it then dropped to £3 039 before the farm was properly established, and has increased to £12 831 in 1902-03.

The average return is about £7 000 more than it was before the Board's work started, equal to a return at 4% on a capital expenditure of £175 000.

From 1895-96, the tonnage outward has increased at the Werribee Station from 7 196 to 41 122 tons in 1900-01, while the tonnage inward has increased from 5 788 tons in 1898-99 to 11 336 tons in 1902-03.

The total average tonnage passing in and out of the railway station has been, from 1895-96 to 1902-03, 32 000 tons, a large proportion of which goes to or from the farm.

A jetty has been run out into Port Phillip Bay, from which vessels drawing 10 to 12 ft. of water can load and carry produce to the Melbourne or Geelong markets. With proper arrangements, the bay carriage should be cheaper than railway carriage.

The farm is well able to provide a very large proportion of the vegetables required for the Metropolitan markets, and with cheap bay carriage, it is very probable that a large area of the farm will be utilised for this purpose.

With the good drainage now provided, and the large area of graded blocks available, long narrow beds could be formed with the machine already on the farm, so arranged that the sewage would

percolate to the roots without ever coming in contact with the leaves. Mr. Thwaites.

These blocks, with proper tree shelter from the prevailing winds, offer an ideal place for raising vegetables on a large scale.

TABLE 25.—Recent Analyses.

	Soluble.								
	Total, inorganic.	Total, organic.	Total, solids.	Lime, Ca O.	Magnesia, Mg O.	Sulph. Anhyd., SO_3.	Iron oxide or albumina.	Chlorine.	Chlorine as sodic chloride.
	Grains per gallon.								
Pumping Station....1	174	35	209	5.6	10.9	.....	0.1	93	158
" " 2	140	19	159	7.8	12.3	.....	7.4	94	156
" " 3	142	96	258	5.3	9.7	.....	6.7	95	158
Werribee.....1	105	29	134	5.9	11.2	11.0	2.9	87	144
" 2	125	54	179	8.7	10.8	12.6	.....	93	154
" 3	144	34	178	8.3	12.2	10.6	7.9	92	152
" 4	164	38	202	8.3	10.1	12.2	5.6	95	157
" 5	162	36	198	Not Det.	9.6	13.2	.....	89	147
" 6	144	48	192	6.1	9.5	11.2	2.8	91	151

	Fats, etc., soluble in Carbonic Dioxide.	Carbon Dioxide, free.	Carbon Dioxide, combined.	Ammonia, free.	Ammonia, combined.	Sulph. Hyd., free.	Sulph. Hyd., combined.	Combined Carbon Dioxide as Carbonate.
	Grains per gallon.	Volumes of gas per 100 vols. of sewage.						Grains per gallon.
Pumping Station.....1	2	10	6	6.0	0.2	0.2	0.9	11
" " 2	1	6	7	5.5	0.3	0.2	0.5	13
" " 3	43*	9	5	3.2	.....	0.6	0.4	8
Werribee.....1	2	12	8	4.5	0.2	0.2	0.9	15
" 2	.....	12	7	5.0	0.8	0.3	0.5	14
" 3	6	12	6	5.4	1.0	1.1	0.4	10
" 4	4	6	3	6.1	0.1	0.8	0.3	6
" 5	3	8	2	3.0	1.0	0.2	0.5	4
" 6	2	10	3	3.5	.....	0.6	0.2	6

Samples collected for six successive days at Werribee, the last three samples 4, 5 and 6 being collected the same day as those at the pumping station.

* High result in this case may be caused by a ball of fatty matter being included in the sample.

Mr. Thwaites.

TABLE 25.—(*Continued.*)

	Insoluble.			Soluble.								
	Organic.	Inorganic.	Total.	Fixed saline.	Organic volatile.	Total solids.	Lime, Ca O.	Magn., Mg O.	Sulph. Anhydride, SO_3.	Chlorine.	Chlorine as Sodium Chloride.
	Grains per gallon.										
November 16th, 1903											
Pumping Station...	15.6	7.4	23.0	176	30	206	3.7	9.1	15.3	103.6	170
Before First Sulphur Station.....	15.8	8.3	24.1	140	17	157	5.5	8.3	9.8	75.8	125
After First Sulphur Station.....	11.5	7.9	19.4	143	19	162	5.8	8.9	9.6	77.0	128
Before Second Sulphur Station.....	12.8	8.7	21.5	148	23	171	6.4	8.8	9.6	84.0	139
After Second Sulphur Station.....	20.8	9.3	30.1	144	22	166	6.3	8.7	9.5	84.0	139
Distribution Head..	.....	.....	.....	144	20	164	6.1	8.3	9.5	88.6	146
Effluents.											
160 S.—15 E.....	.....	.....	.....	357	38	395	12.9	32.6	25.5	203	352
280 S.—25 W.....	.....	.....	.....	190	26	216	9.6	14.7	12.3	107	176
" 15 E.....	.....	.....	.....	585	52	637	19.1	48.3	40.5	340	561
" 55 E.....	.....	.....	.....	790	69	859	23.7	66.6	58.5	455	750
270 S.—95 E.....	.....	.....	.....	1060	140	1200	37.9	95.4	74.6	625	1030
December 2d, 1903.											
Pumping Station...	20.7	11.2	31.9	138	20	158	7.0	8.1	12.2	78.0	129
First Sulphur Station.....	10.4	10.9	21.3	173	45	218	8.2	10.0	14.2	100.1	165
Outfall Sewer.....	11.7	11.5	23.2	141	19	159	6.4	8.7	10.7	83.3	137
Distribution Head.	14.3	11.2	25.5	113	15	128	5.2	4.1	6.2	65.5	107
Average Sewage.											
March, 1903.....	7.2	4.2	.....	175	30	.....	7.0	13.0	11.8	102.9	169
July, "	17.6	6.9	.....	157	30	.....	7.1	11.6	12.3	91.9	152
November, "	12.9	8.1	.....	149	21	.....	5.6	8.7	10.5	85.5	141
Sewage.											
Maximum, 1903.....	14.9	6.9	21.8	200	36	230	8.1	13.8	13.8	112.7	186
Minimum, "	0.3	1.3	1.4	146	20	164	5.5	8.3	9.3	75.8	125

The chlorine as sodic chloride has dropped very considerably in the sewage, the average for various years was:

1898, 438 gr. per gal.; 1900, 303 gr. per gal.
1899, 255 " " " 1901, 247 " " "

The determination at the pumping station in 1902 varied from 255 to 184, and in the outfall sewer from 236 to 142. During 1903, the pumping station varied from 170 to 129 and the outfall sewer from 186 to 125.

The sewage is becoming more normal year by year, the brackish water from the sub-soil gradually reducing in proportion to the sewage.

The effluent from the farm drains is very much more impregnated with salt than the sewage carried on the farm. The very

efficient system of drainage is rapidly improving the soil by dissolving the natural alkalis in it. Mr. Thwaites.

Mr. Avery, the Board's chemist, has prepared the following statement in connection with the determination for 1903:

"I have attached the results of the special samples of sewage collected last week. As the results show, four different sewages have been obtained from different parts of the outfall sewer, so that the results cannot be taken to show progressive changes taking place in the sewage, but serve well to show the very irregular character of the sewage. The sample taken at the head of the outfall sewer gives very high results all through; while that taken at the distribution head at Werribee is exceedingly low. This may possibly be accounted for by the addition of storm water to the sewage at the beginning of the week. I have added for the sake of comparison the average results of the different lots of sewage analysed during the year (1903) and the maximum and minimum amounts present in any individual sample during the same period. Irregularity in character prevents any strict comparison, but taken generally there is a diminution in dissolved material throughout the year. More numerous samples would have to be examined to decide whether this diminution is actual or the accident of samples. I am inclined to think that the diminution is actual.

"The gas contents (ammonia and sulphuretted hydrogen only were determined) show a marked decrease from former samples. This agrees with the comparatively odorless character of the sewage at present.

"The gas present depends on the age of the sewage, and I have found that keeping for one day greatly increases the amount present, so that it is difficult to obtain reliable figures.

"Addition of preservative, such as formaline or phenile, seems to prevent further decomposition to some extent and render the results more reliable.

"The samples last week were six hours old before determination."

The bacteriological analyses obtained in July and December, 1903, as reported by J. R. Bull, M. D., Demonstrator of Bacteriology, Melbourne University, are given in Table 26.

"The sulphurization of the sewage has been discontinued one week prior to collecting the samples in December, and the bacteriological results contrast strongly with those obtained in July, when sulphurization was in full swing.

"In spite of the relatively low bacterial count at the pumping station in December (344 000) the number ran to over 5 000 000 at the distribution head, whereas in the previous examination there appeared to be a tendency to progressive diminution from 2 880 000 at the pumping station to 1 600 000 at the distribution head. The contrast in the examinations is highly suggestive of the inhibitory action of sulphurous acid in bacterial growth.

"As regards final purification of the sewage, the December re-

Mr Thwaites. sults are highly satisfactory, the average of five samples of effluent being 14 600, corresponding to a percentage reduction of 99.7, as a result of the various factors at work on the farm.

"These results are much better than those obtained in July when the effluents averaged as high as 250,850, equal to a purification of 84.4 per cent."

TABLE 26.

	Micro-Organisms per Cubic Centimeter.	
	July 14th-15th, 1903.	December 2d, 1903.
Pumping Station	2 880 000	344 000
Before No. 1 Sulphur Station	1 920 000	.....
After No. 1 Sulphur Station	1 800 000	1 120 000
Before No. 2 Sulphur Station	2 000 000	.....
After No. 2 Sulphur Station	1 200 000	.....
Outfall Channel	.....	1 280 000
Distribution Head	1 600 000	5 200 000
Effluents.		
160 S.—15 E	.....	18 030
280 S.—25 W	700 000	.....
15 E	14 800	8 600
55 E	48 600	14 800
270 S.—95 E	240 000	18 800

The reason for the July results being high was that the surplus winter sewage was being dealt with by sedimentation and percolation in filtering pits rather than on the grazing areas.

The Metropolitan Sewage Farm of Melbourne considered as a machine for purification of sewage is doing its work remarkably well. There is a very considerable return to the Board from the farm, in fact, for the financial year, July 1st, 1902, to June 30th, 1903, the returns paid interest on cost of purchase of land and preparation and the working expenses of the farm and left £2 000 profit. The year, 1902-03, was an exceptionally favourable year for the Board by reason of the drought. The water supply revenue was high, as there are so many private gardens to the Melbourne residences, which are irrigated. At the same time, through the drought, sheep were bought cheaply and sold at a high price.

Although such good returns as 1902-03 must be considered exceptional, the results for 1901-02 were not, and the debit balance for that year was only equal to 0.63 pence in the pound on the value of the property sewered on June 30th, 1902.

Mr. Hooper. H. Ross Hooper, M. Inst. C. E., London, England.—Great credit is due to Mr. Fuller for his valuable contribution on the present position of sewage disposal in the United States.

There is one question in particular raised by him which is of the

greatest importance to American engineers, *viz.*, the consumption of water per head in America. As given by Mr. Fuller, this averages 135 gal., varying from 50 to 300 gal. The difficulties from such a water consumption are obvious, both on account of their variability and their magnitude, and they make it hard for the engineer to design economically sewage purification works upon the known data and standards of to-day. It will, therefore, rest with the engineer to enforce a reasonably careful use of water, not only to keep the water-works within practical limits, but also to allow the sewage purification plants to be constructed on economic and, therefore, commercial lines. Mr. Hooper.

In England the question of sewage purification has received the greatest attention from the various municipal and local authorities, and the results obtained in numerous cases are most encouraging.

Over all local authorities, be they county councils, corporations, urban or rural districts, there is one controlling authority, the Local Government Board, whose jurisdiction is final in all matters of local government.

As no local authority is allowed to raise a loan for any public works without a private Act of Parliament or sanction from the Local Government Board, it follows that the approval of the Board is necessary to carry out works of sewerage or sewage disposal, and the Board has, therefore, formulated certain requirements which may be regarded as the established principles adopted in England, of which the following is a summarized outline.

Sewage outfalls may be divided into three heads:

1.—Discharging directly into the sea;

2.—Discharging into tidal waters;

3.—Discharging into streams and rivers.

In regard to sewage discharging into the sea, no purification is required at present, although, in view of the apparent danger to the shellfish industry in certain districts, it may become necessary to adopt some purifying treatment. The sewage is usually discharged into the sea in such manner that no nuisance is created upon the foreshore. This may be effected by discharging at a considerable distance from the town, or on the ebb tides by means of storage tanks or storage sewers.

It is usual in the case of discharge into tidal waters to require some process of purification, depending on local conditions to a certain extent, and the means adopted are much the same as in the case of streams and rivers.

Under the Rivers Pollution Act, 1876, no person is permitted to discharge, into any stream, any matter which may cause a nuisance; the purification of all sewage, which must eventually be discharged into some natural watercourse, becomes, therefore, necessary. To

Mr. Hooper. effect this has of course taken time, but the improvement has been both steady and effective.

The different processes of sewage purification in England may be subdivided as follows:

a.—Broad irrigation;

b.—Chemical precipitation;

c.—Bacterial filtration.

a.—Broad Irrigation.—This process, as the term implies, consists in the discharge of crude sewage over an area of land by carriers, ditches, etc. The requirements are that the sewage farms, as they are called, shall be of an area proportionate to the number of inhabitants to be sewered in the ratio of 1 acre per 150 persons. The suitability of the soil will determine the efficiency of this treatment; light sandy and gravelly soils being the best, while heavy clays are of little or no practical use. In many cases, it is necessary to underdrain the land to collect the effluent, while in the best conditions there is no effluent at all.

In cases where the sewage is first treated in a septic tank, the area of land required is reduced to the proportion of 300 persons per acre.

On these sewage farms, crops may be raised, cattle fed, etc., in some cases with good financial results.

In the City of Nottingham, where the Corporation has a large sewage farm, the total sewerage rate, including all fixed charges and maintenance, etc., is under 5 pence in the pound.

b.—Chemical Precipitation.—This practice, though still general in many places, has of late years been somewhat superseded by the anaerobic bacterial treatment. The process consists in precipitating the sludge in large tanks by means of chemicals, after which the sewage is further purified through contact beds or filters. The disadvantage lies in the large amount of sludge to be dealt with; it has to be pressed into cakes, and disposed of to farmers, but it cannot be said to possess any real market value.

c.—Bacterial Filtration.—This process may be regarded as the most advanced treatment to-day and consists in first discharging the crude sewage into septic tanks whose anaerobic action breaks up and liquifies the sewage, rendering it easy of subsequent filtration.

The design and capacity of these works are based upon the following data: The dry weather flow (D. W. F.) of the sewage is determined by multiplying the gallons of water consumed by the number of the inhabitants to be sewered. Thus a town of 50 000 population using 40 gal. per head *per diem* will have a D. W. F. of 200 000 gal.

The Local Government Board requires that where the system is "combined" (*i. e.,* surface water goes into the sewers) three times

the D. W. F. shall be fully treated, but where the system is "sep- Mr. Hooper.
arate," then only twice the D. W. F. shall be fully treated. The remainder of the flow up to three or four times, according to whether the system is "combined" or "separate," is treated in what is known as storm-water filters, and any surplus beyond six times the D. W. F. may go untreated into the stream direct, as the dilution is considered to be reasonably safe.

On these data, therefore, the volume of sewage to be treated is based.

The septic tanks, which are usually covered, as the anaerobic treatment is considered to be more efficient in the dark and when the surface scum is not broken up by wind, have a capacity of from $\frac{3}{4}$ to $1\frac{1}{4}$ the D. W. F., proportionate to the volume of sewage to be treated.

The filters which are usually constructed of clinker are of a minimum depth of 4 ft., over which the sewage is continuously (hence called continuous filters) distributed by means of troughs or automatic revolving sprinklers. These filters must have a capacity equivalent to 56 gal. per 24 hr. per sq. yd. per ft. in depth, which principle also regulates the size of the contact filters.

The contact filters differ from the continuous filters, however, in the periods of working, which are usually in three 8-hr. cycles (*viz.*, 1 hour filling, 3 hours full, 1 hour emptying and 3 hours rest), while their depth is not proportionate to the efficiency of working and may be from 2 ft. upwards.

In all cases the Board specifies, in addition to the above filtration, that a final treatment on land is essential, the area of which land is in the proportion of 1 acre per 1 000 inhabitants. In exceptional cases, however, when land is not reasonably obtainable or of a very unsuitable character, it may be dispensed with, but in such cases the capacity of all the filters must be not less than 28 gal. per 24 hr. per sq. yd. per ft. of depth.

Storm-Water Filters.—These filters are usually shallow pits in the ground, 3 ft. deep, filled with clinker, and must have an area of 1 sq. yd. for each 500 gal. per 24 hr., and are underdrained in the usual manner.

Nuisances Arising from Sewage Disposal Works.—These may be said to be practically *nil,* except in the case of insufficient attention on the part of employees, and the fact that many hospitals, asylums, recreation grounds, etc., often adjoin the works without any bad effects, is sufficient to prove that they are not necessarily dangerous neighbours.

In the purification of sewage, it is not pretended that a potable water is to be the test of efficiency, the aim should be to produce an effluent, non-putrescent, inodorous, and colourless, and to-day this

Mr. Hooper

is being effected in hundreds of towns and villages in England, through the processes outlined above.

In effect, therefore, crude sewage by natural means, as outlined above, without the aid of machinery or chemicals can now in a few hours be so purified as to be robbed of its dangerous elements and rendered innocuous.

Mr. Rosewater.

ANDREW ROSEWATER, M. AM. SOC. C. E., Omaha, Nebr.—There is a large unexplored field open for investigation and discussion of the question relating to the treatment of sewage through the agency of contact beds or filters, after subjection to bacteriological action within septic tanks.

In 1898 the speaker designed and supervised the construction of a system of sewerage with septic tanks and filter plants for the City of Independence, Mo. This city has a population of about 8 000, and is practically a suburb of Kansas City. After passing through the septic tanks, the sewage was designed to pass over a series of three filter beds, one above the other, but about 8 in. apart. On approaching the first layer, the sewage falls over several steps arranged to develop slight aeration, and then, after spreading over the surface and passing successively through each layer of coke breeze, the sewage falls in drops or sprays through the intermediate air space, thus insuring very thorough aeration. There has never been a chemical or bacteriological examination or report made on the effluent from the works, but some two years or more after their completion, Mr. Pendleton, the local engineer, in a letter stated that the effluent was so like spring water that he drank of it several times without being able to distinguish it from spring water, and that the cattle from the adjoining farms came to the filter outlet to drink the effluent in preference to the turbid creek water into which it flowed.

This process of filtration and aeration requires very little attention. The report of the engineer in the case cited was that, for the three years following its use, an average of only $12 per year had been expended at the plant. The question, which suggests itself in connection with this method and that of contact beds, is one of relative possible results for given areas and quantities of materials used. The contact beds are, after all, only designed to bring the effluents in contact with the air spaces contained in the coke, broken stone or gravel used for oxidation, and, for the purpose of higher purification, secondary contact beds are recommended by many engineers. The intervals between contacts within the same beds are to give the surface of the material comprising these beds a chance to rest, or more appropriately speaking, to enable renewed atmospheric contact for oxidizing the materials remaining on the surfaces of the coke or other materials used, by affording time to refill the spaces with fresh air.

Mr Rosewater.

In the case of the filter described, no devices for turning off or on the flowing effluent from the septic tanks are necessary, as the filter affords ample opportunity for air contact not only through the fall of the liquid through the intermediate spaces, but, inasmuch as there is little flow each morning between midnight and 5 A. M., there is ample time for recharging the voids of the respective layers with fresh air regularly every twenty-four hours. In view of this, the question to be determined is how much air is needed for purification, and what relative thickness of filtering medium and air space is equivalent to a given thickness of contact bed? We have many advocates of the second contact bed, but we have no definite data that enable us to arrive at any formula by which we can determine with any precision what effects the second contact-bed treatment develops for definite quantities of materials used. The American Society of Civil Engineers, through some committee, or our universities which have liberal endowments, should conduct systematic experiments that would assist in these conclusions.

In general, the conditions for management and deductions in the United States vary materially from those which obtain abroad, and in a few exceptional States, like Massachusetts, where the laws are stringent relative to the discharge of sewage into streams and to the proper treatment of sewage to preclude stream pollution. Engineers in the United States frequently turn over to municipal authorities properly designed and constructed systems of sewer and disposal plants, which, owing to the inefficiency of those left in charge, result unsatisfactorily. The subsequent official reports from such sources are utterly unreliable, and conclusions drawn from them often lead to failures. On the other hand, the management of sewer systems, as of other municipal plants abroad, is entrusted to skilled persons whose reports can generally be relied upon because the management is in harmony with the outlined work of the designing engineer.

A disposal plant within the City of Omaha, now undergoing completion, provides for the purification of sewage for 20 000 people. In order to economize and produce uniform results during the development of that population, instead of one large septic tank and filter bed, the plant is designed in a series of batteries consisting of one septic tank and one filter, with capacity for 4 000 inhabitants to each series, that is, practically for 800 dwelling connections. Thus, at the outset, one-fifth of the entire plant will be in use, and when over 800 dwellings are connected, the second of the five groups or batteries will be constructed, thus developing, as near as may be, uniformity in the flow per given area of tankage and filter per given population.

Unsatisfactory results from septic tanks, due to excessively long

Mr. Rosewater. retention of sewage in them, are often recorded. Septic tanks may be designed correctly for a population of 20 000, but if the number using such tanks for the first few years is one-fifth, or less, of the number for which they have been designed, they may prove disappointing and be prematurely condemned.

A year or more ago, reports were published of careful experiments conducted at Cornell University upon the exposure of sewage to septic action for different periods of time, concluding with a recommendation that the best average results, chemically and bacteriologically, would likely develop from six and eight hours' exposure. This being true, it is essential to design the septic tanks so that the sewage will not be exposed there two or three days, a result which would naturally follow the design of a tank with capacity for a population which may be expected ten years after its construction.

Mr. Hazen. ALLEN HAZEN, M. AM. SOC. C. E., New York City.—Mr. Fuller's paper puts the whole subject of sewage purification in such compact and convenient shape, and at the same time the treatment is so adequate, that it will be a standard work of reference on this subject for a long time to come.

There is one possibility in the way of sewage purification which has often struck the speaker as capable of being developed to a much greater extent than it has been, and that is, the treatment of sewage at a low rate upon land with a flat surface and well adapted to the distribution of sewage, but not pervious enough to be capable of taking sewage at a high rate.

Where the sandy and gravelly glacial drift exists, that is, in New England and across a good deal of the northern part of the United States, the opportunities for sewage purification in connection with it are so favorable that it seems destined always to serve as the basis of a large part of the sewage purification where it exists. This material is often or generally so pervious that sewage can be applied to it and satisfactorily purified at all seasons of the year, in winter as well as in summer, and in wet periods as well as in dry periods.

South of the glacial drift, the conditions of sewage purification are generally more difficult. The soil is often far less pervious, but there are large areas of comparatively flat land, particularly in the densely populated Middle States, on which sewage could be applied with a minimum preparation of the land, and in dry weather and in summer, this land is capable of receiving and purifying a fair amount of sewage.

Where the purification of sewage is necessary to protect a water supply taken from the stream below, a summer and dry-weather treatment is clearly inadequate; but where the purification is re-

quired to prevent a local nuisance in the stream into which the sewage flows, and where this is practically the only reason for purification, then the purification is most needed in summer and in dry weather; frequently it happens that this is the only time that it is required. Mr. Hazen.

Now it happens that this period, when the conditions are most likely to make a local nuisance, is precisely the period when the land is most capable of receiving and purifying sewage, and it is further the season when crops, if grown upon the land, would be most benefited by the application. It therefore seems that the use of a summer dry-weather treatment in many such cases would be advantageous, and cheaper, and perhaps also more effective, than the septic tanks and entirely artificial filters which might otherwise be used.

H. N. Ogden, Assoc. M. Am. Soc. C. E., Ithaca, N. Y.—It is of course impossible in a paper of this sort, reviewing as it does in so comprehensive a way the present status of the different methods of sewage disposal, to describe the details of the several processes. Any attempt in this direction would prolong the paper to an extravagant length. Yet the period of time which sewage should remain in a septic tank, both maximum and minimum, seems to the speaker so vital a matter as to determine almost, if not quite, the successful future of this method of disposal. No definite information, so far as the speaker knows, is available, and while, in England, tanks are made to hold 1½ days' flow, and while engineers in the United States are building them (even with the greater rates of flow in this country) to hold 24 hours' flow, other engineers, it seems, are equally successful with tanks holding as little as 4 hours' flow. It is conceivable that a community might be able to find money to build a tank for one storage and not for the other, making this method feasible, or not, by the solution of the question here propounded. Again, the hourly variation of flow in a tank of small capacity must subject the flow to a varying bacteriological action, so that the effluent at night will be several times as stale as that passing the tank during the middle of the day, and the effect of this difference on the general purification of the plant may be to cause a daily nuisance during that period of heavy flow. Again, the flow of sewage through a newly built tank is never that for which the tank is designed, and the relatively small flow at the start may cause the effluent to be so stale as to fill the filters with toxines, and so prevent a proper nitrification. These two questions, *viz.*, the minimum effective rest period in the tank and the permissible elasticity of any assigned rest period seem to the speaker to be so fundamental and comprehensive as to determine the practical value of the septic treatment for this country. Prof. Ogden.

Prof. Ogden. The experiments, referred to by Mr. Rosewater as having been carried on at Cornell University, were made, under the direction of the speaker, in 1900, by R. B. Williams, Jr., Jun. Am. Soc. C. E. The plant consisted of five tanks, each discharging on a filter bed designed to act at the rate of 1 000 000 gal. per acre per day. The tanks allowed the sewage to flow at rates corresponding to rest periods of 2, 4, 8, 12, and 24 hours, and it was hoped that analyses of the raw sewage and of the effluents from the several filters would indicate the economical rate of tank flow. The tanks were allowed to run at their designed rates for two weeks before analyses were started and for three weeks more with daily analyses. The relative purification effected, as determined by the oxygen-consumed test, was as follows, the amount, in parts per million, for the raw sewage being 19.04:

Rest period.....	2 hr.	4 hr.	8 hr.	12 hr.	24 hr.
Oxygen consumed.....	8.48	8.76	8.18	7.55	7.18
Percentage of purification..	56	55	57	61	62

The relatively high value for the purification effected by the 2-hr. tank has since been found to be due to a leak in that tank whereby the sewage finally passing to the filter had been acted upon for more than the period intended. The inference to be drawn from the experiment, assuming that the septic action had been under way for sufficient time, is that the gain in purification in a tank holding 24 hours' flow is inconsiderable and not warranted by the increased expense due to the added size of the tanks. From an economic standpoint, it is the minimum length of time for storage which engineers should know, and it is hoped that the experiments at Columbus may throw an abundance of light on this point. Mr. Dibdin, the English chemist, believes that no septic action takes place unless the solids to be acted on remain in the tank at least eighteen hours. It may be that, with the comparatively dilute American sewage, the amount of organic matter in solution is so small that there is no objection to turning it directly on filter beds, the solids in suspension being taken out by sedimentation in the so-called septic tank, and there acted upon at leisure by the anaerobic bacteria.

Mr. Hanley. E. J. HANLEY, Esq., St. Louis, Mo.—The speaker has had two rather novel experiences in the past year, which, to some extent, answer the inquiries made by previous speakers. A small septic tank was put in near Chautauqua, Ill., the sewage being let into it in June, 1902. It received the sewage from a Chautauqua Assembly having a population varying from 500 residents to a visiting population of 6 000 on certain days. We got very good clarification in about ten days, which continued during the Assembly and until the summer residents moved away in September. The tank then re-

mained dormant all winter, and the following June (1904) the speaker examined it and found that there was practically no change in the appearance of the scum since he had seen it last, in August, 1903. When the tank was first opened the odors were no worse than when it is doing good work. Mr. Hanley.

The speaker saw the tank in September, 1904, and also two or three times during the Chautauqua Assembly, and, during that time, he found that the effluent was practically clear water without offensive odor. This covers the point raised by previous speakers, *viz.*, that the tank was practically out of commission and full of old sewage, and when it started up again with a fresh supply, the purification was apparently just as great as before.

The speaker's second experience in the same line was at Boulder, Colo., where a small septic tank was built on his plans to take care of the sewage from a school of 200 children. The tank was used during one school term and gave very good satisfaction. During the following vacation, it was out of commission, remaining full of sewage and having no attention paid to it. When the new school term began, the sewage was discharged into it as before, and we have just received a report that at a distance of 15 ft. from the tank there was no odor from the effluent. The school authorities have sent us a bottle containing about 8 oz. of the effluent, and there is absolutely no deposit. It takes about 12 hours on an average for sewage to pass through the tank.

H. Birch Killon, Assoc. M. Inst. C. E., Manchester, England.— Mr. Killon.
Referring to the remarks of previous speakers as to the best capacity for the septic tank, it may be observed that there has been a tendency on the part of some engineers in England to make the septic tank of a capacity equal to 1½, 2, or even more, days' dry-weather flow of sewage. The excessive septic action which is developed in such a large tank produces a bad smelling effluent, difficult to treat in bed or filter, and much black growth (the result of putrefaction) passes from the tank and tends to choke up the filter. It is now generally conceded that the fresher the sewage the more easily it is purified, and that screening and sedimentation are the only preliminary processes which are desirable for a town's sewage which has passed through a considerable length of outfall sewer in which the necessary septic action has taken place.

English practice differs from the American principally in the attempt by the former to concentrate the purification works on a small area of contact beds or continuous filters instead of a much larger area of sand filters dosed intermittently.

It has been found in England that given the best possible conditions, *viz.*, land of light sandy loam overlying gravel and sand, only some 10 000 to 20 000 Imperial gal. per day per acre of the total

Mr. Killon. irrigable area can be purified, whereas, allowing for double treatment in contact beds, some 500 000 gal. per day per acre can be purified to an extent sufficient to comply with the usual standards; and in continuous filters equal purification of 1 500 000 Imperial gal. per day per acre can be effected.

A purification amounting to 90%, as measured by the albuminoid ammonia, and 89%, measured by the oxygen absorbed, is being effected in a single filter (not tank plus filter), fed at the above rate, the sewage being distributed over the whole surface by a new type of automatic revolving sprinkler, by which uniformity of distribution over every square foot to within 10% of the mean delivery is now effected without the offensive spraying due to fixed jets or the difficulties incident to the use of revolving distributors of the "Barkers mill" or reaction wheel type, or the cost of power-driven distributors.

Mr. Hering. Rudolph Hering, M. Am. Soc. C. E., New York City.—One point suggests itself to the speaker, namely, why we do not and will not have so many sewage disposal works in the United States as in Western Europe. This is due to the fact that we have larger rivers, into which we can dispose of our sewage by the cheaper method of dilution. Our rainfall is just about twice as great as in England, therefore, our rivers, for the same drainage area, are about twice as large, and, consequently, we have better opportunities for this method of disposal.

The speaker would also like to say a word regarding the oyster question. This is now being given serious attention. It seems that it will be solved as a financial question, namely, as to whether the city is to purify its sewage or whether the oysters that may be polluted by the same will have to be grown elsewhere. The question has been raised seriously already in Baltimore and in New York. So far as New York City is concerned, it is impracticable to purify its sewage, including that of the suburbs of the adjoining State and comprising now altogether about 5 000 000 of people. It is, therefore, unreasonable to think of saving the few oysters that may be obtained from New York Bay. In Baltimore, the proposition to discharge sewage by dilution into Chesapeake Bay has so far been defeated on the ground that the oyster of the bay would be injured. In the latter city, there is an opportunity of purifying the sewage on the land at a fairly economical rate, but also at a greater expense than by dilution. It is still a question whether the value of the oyster in the upper bay justifies the greater expense of sewage purification.

It should also be mentioned that while the question of sewage disposal is in its infancy in our country, yet the United States has done and is doing a great deal to settle this question. In the first

place, we have the results of the investigations of the Massachusetts State Board of Health, demonstrating the scientific foundation of sewage purification. Lately, the City of Columbus, Ohio, has inaugurated, at a large expenditure, an experiment station for the purification of sewage by the more modern processes, of which so much is now said, and which we desire to see further developed. Within a year that city will probably give some valuable results to the Engineering Profession. No city in Europe has made experiments on such a scale, and, therefore, although we have but a few sewage purification works, we should hardly be considered far behind Europe in these matters, at least so far as establishing a scientific basis for them is concerned. Mr. Hering.

ROBERT SPURR WESTON, ASSOC. M. AM. SOC. C. E., Boston, Mass.— The speaker has received the impression from the remarks of a previous speaker that air is believed to be a direct oxidizer of sewage. This impression should be corrected. Bacteria are the direct agents in the decomposition of sewage. One great group of bacteria, the anaerobies, breaks down organic matter by a process of liquefaction called hydrolysis, transforming albumens to peptones and gases, and dissolving, by bacterial life-products or enzymes, much of the suspended matter in the sewage; while another great group, the nitrifying bacteria, requires air to maintain the growth of the bacteria, and the by-product of this growth in the presence of the organic matter in sewage is the oxidized nitrogenous matter, in the form of nitrate or "saltpeter." Mr. Weston.

Therefore it is not literally true to say that air oxidizes sewage. One should say instead that air supports the nitrifying bacteria, which bacteria absorb organic nitrogen and air, and give off mineralized nitrogen—nitrate.

M. O. LEIGHTON, ESQ., Washington, D. C. (By letter.)*—Mr. Fuller has noted that the sewage disposal plants of the South and West are operated almost without exception for irrigation purposes, and that little attention seems to be given to the actual purifying effect of the processes themselves. The geographic distribution of sewage purification plants, mentioned in Table 1 of Mr. Fuller's paper, shows clearly that it is only in those parts of the United States where municipalities are numerous and situated near each other that there has been any scientific attempt to purify sewage. In other words, the efforts which have been made to render sewage harmless are not as much the result of a disinterested effort to advance the cause of hygiene as of the objections of the next door neighbor to the presence of unpurified sewage. Mr. Leighton.

The sewage disposal plants of the West and Southwest, in the arid and semi-arid regions, afford almost nothing in the way of

*Chief, Hydro-Economic Div., U. S. Geological Survey.

Mr. Leighton. exact information with reference to the efficiency of any method of purification. Generally, the plants are merely head-gates to irrigation systems and should be regarded as such. There are no standards of purity to which an endeavor is made to bring the effluent, and it is sufficient to say that hardly any of these plants would be maintained were not the sewage of pecuniary value.

The value of sewage for irrigation in arid lands is based, in a measure, upon the fertilizing ingredients which it contains, but principally because the sewage is wet. It is the water rather than the fertilizer which is needed in those countries, and in some portions, especially within the last four or five years, the drought conditions have become so acute that water in almost any form and condition will suffice for irrigation and even for domestic purposes.

The feature of sewage disposal in the arid regions is, therefore, more important than is generally believed. Under the Irrigation Act, by which all money received from the sale of public lands is diverted for the construction of irrigation systems, there has been and will be in the future a remarkable increase of population in arid countries. This will inevitably result in the question of sewage disposal becoming more and more important, and it is probable that the country must pass through, within a short period, the various stages of sewage development, which, in the East, have required several decades. Now, in that country, one cannot choose a source of water supply; between eminent engineers there is never any dispute, so common in the East, as to which is the best. Usually, there is only one, and the inhabitants take it as it comes and feel fortunate that it is available. As is frequently the case, the only source of water supply in those countries is the irrigation canal which as frequently is the sewage outlet for communities and ranches. In fact, the irrigation canal seems to be used promiscuously as a source of domestic supply and as a sewer. At the present time, the country is not thickly settled, and the main object is to secure water of almost any quality, and it is safe to predict that the results of these practices will be as fatal as they have been in other parts of the world. The purification of sewage is, therefore, of great importance in these countries, especially purification on a small scale for one ranch or a small group of houses, and it is well worthy of the study of engineers.

Mr. Alvord. John W. Alvord, M. Am. Soc. C. E., Chicago, Ill. (By letter.)—In reviewing Mr. Fuller's paper, one cannot but be struck by the wide range of the subject and the fragmentary character of the data which have accumulated. The paper is an admirable attempt to sift out and correlate in brief and comprehensive form a *résumé* of existing information which is most welcome at this time.

Sewage disposal data have been developed by the researches of

the hydraulic engineer, the chemist and bacteriologist, the physician and sanitarian, and the municipal officer; and their disconnected character arises from the fact that each of these professions has made its contribution along lines with which it is most familiar, and without regard to its proportionate value to the subject as a whole. Mr. Alvord.

In addition, it may be said that the theory of sewage purification is far ahead of the practice, and, consequently, its literature is full of speculation by those whose interest in the subject has outrun the ascertained facts. So closely is speculation interwoven with safely ascertained conclusions that it is sometimes difficult to distinguish what is established as truth, and what is propounded as possibility. Even among experts there is a disposition to a constant change of viewpoint, especially with reference to the efficacy and comparative economy of some of the newer biolytic processes.

This arises partly because the addition to our list of available methods was quite rapid from 1895 to 1900, and partly because there are so few reliable data published as yet on plants of sufficient size, which give clearly the cost and effectivenes of different methods under discussion.

The writer, having been obliged from local circumstances to deal more largely with what may be termed the newer biolytic processes, will endeavor to confine his discussion of Mr. Fuller's paper to some observations on those methods, and outline what seem to be the facts with regard to them.

Prior to 1896, the Massachusetts State Board of Health had worked out an efficient method of sewage purification for localities situated within the area of glacial drift, or fortunately supplied with a porous soil, and several successful plants were put in operation in that section of the country.

Unfortunately the conclusions of these studies, while extremely valuable to the New England States, did not materially aid in the practical solution of the problem for places where conditions of soil were not similar.

Large sections of the South and Central West are quite devoid of sand and gravel, and, in spite of the liberal studies at the Lawrence Experiment Station, sanitary engineers of the driftless areas found themselves quite unable to utilize such results to any considerable extent.

The work of the Massachusetts Board, however, gave a tremendous impetus to the subject of sewage purification in the United States, and when, about 1897, the first results of English studies on more rapid biolytic methods became available, it was only natural that practice in alluvial states was quick to appreciate their application to prevailing conditions. Naturally, it has followed that the

Mr. Alvord. West has adopted these methods and is, for the most part, studying and developing them at first hand through full-sized installations.

The period prior to 1900 was fruitful in original work, both in England and this country, in installing new methods and in studying them. Opinions varied widely as to the various forms which the new methods took, and sanitary engineers, whose practice followed the experimental work at Lawrence, were at first somewhat skeptical of rapid biological purification.

The writer, reporting on the sewage disposal at Columbus, Ohio, in 1898, when this stage of thought was uppermost, was good-humoredly taken to task for rashness in advising experimental contact beds and including the septic tank among studies made. Since that time both the septic tank and contact beds have risen and fallen in scientific favor, and now are apparently rising again. Such are the fluctuations of mind to which the best of us must plead guilty in seeking after truth when facts are few and far between.

Since 1900 it does not appear that many new ideas have been added to existing methods, but the period has been fruitful in close and diligent study on the nature of the processes and their adjustment, while a very considerable and satisfactory number of full-sized installations in this country are now giving unusual opportunities to collect data as to first cost, economical operation, and relative efficiency of the different forms of purification.

None but the most general deductions can be drawn from this information, which is not yet complete enough to classify. Nevertheless, those who have given the matter much study, note some general tendencies which are clearly discernible, and the formulation of which will aid in further research.

It must always be realized that the most valuable information will be secured from the operation of full-sized working plants. By a full-sized working plant is meant one dealing with a sufficient amount of city sewage so that additional population would economically require its reduplication in working units rather than any actual alteration in size or variation in arrangement. Such a definition would appear to include plants serving populations below 3 000, and it would seem rather regrettable that this limit has been made necessary in Mr. Fuller's paper, as its use excludes from his list many valuable and interesting plants in the Central West, which are doing excellent work, and which would serve added populations by a mere reduplication of units.

With the results of some of these plants in mind, it would also seem that Mr. Fuller had been conservative in placing the quantity of sludge retained within septic tanks at one-third of the total quantity entering the tank. It is greatly to be regretted that the smaller municipalities, in which generally septic installations have

Mr. Alvord.

been made, do not feel able to afford closer supervision and more frequent chemical analyses, so that some exact statement could be made as to this particular matter.

The writer has designed and constructed eleven septic tanks for small cities, besides minor installations, all of which have been in operation two to three years. In only one of these tanks so far has there been evidence that the capacity of the tank was being so reduced by the accumulation of sludge that its removal would be necessary in the near future. This tank, which is situated at Lake Forest, Ill., has been in operation exactly 2 years and 9 months or 1 025 days. As nearly as can be calculated there are about 21 tons of solids now in the tank, which reduces its total effective capacity considerably.

Since the tank has been in operation, analyses of the raw sewage have been meager and some of them noticeably defective in the care taken in collecting the samples. A review of all available information, however, would place the total suspended matter entering the tank at about 80 g. per capita per day. This will mean that about 181 tons of suspended matter have passed into the tank since it was put in operation. And if we assume only 60% moisture for the partly wet and partly dry sludge now within the tank, we would still have only 21 tons remaining in the tank at this time, which is only one-ninth of the original solids.

Of the other ten tanks mentioned, four have been in operation a year longer than the Lake Forest tank and are still without an embarrassing collection of sludge. Other tanks under observation in this section of the country are giving equally good, if not better, results, and it is a theory of the writer that by a careful proportioning of capacity of tank to the quantity of flow, together with the ability to produce some regulation of this proportion, the accumulation within the septic tank can be kept at a very much lower average figure than that mentioned by Mr. Fuller.

Mr. Fuller further states:

"The idea is sometimes advanced erroneously that the septic treatment of sewage is confined to the period occupied by the flow of the sewage through the tank. This is not so, as the controlling features are that the rate of flow, or velocity, must be such that there is deposited on the bottom of the tank a substantial proportion of the matters in suspension. In this accumulated sediment upon the bottom of the tank bacterial action becomes established, which gradually converts the suspended organic matter into dissolved matter, and the latter in turn is converted to gaseous constituents."

The writer is constrained to dissent from portions of the above opinion, and believes that, in a rough general way, septic action is

Mr. Alvord. nearly proportional to the period occupied by the flow through the tank.

The basis of this opinion is found in the fact that sedimentation in septic tanks, with ordinary forms of domestic sewage, is found to be rather incidental for the reason that the period of rest in ordinary practice is too short to be effective for deposit, and the further reason that the matters in suspension have the same, or very nearly the same, specific gravity as water. Sedimentation, therefore, does not commonly occur to any great extent in the form we are familiar with in studies of turbid waters.

The larger particles of organic matter contained in sewage are ordinarily lighter than water, and a great proportion of them float to the surface of the tank. It is a matter of common notice that surface accretion forms much faster than bottom deposit in the septic tanks now under observation.

It should be remembered also that the larger number of septic tanks now in use in this country, at least, are connected with the separate system of sewers, in which grit from street washings or heavy rain is quite absent, and is minimized also from other sources.

Undoubtedly some mineral matters which are present in sewage serve to carry to the bottom of the tank a proportion of the organic solids along with some of the fibrous and cellulose tissue. The proportion of organic solids which is carried to the surface, partly remains there, but a very much greater proportion, which is split up into the form of finely divided matter from the larger solids (possibly by the action of gas formations), is found uniformly all through the body of the liquid from the top to the bottom, and is also distributed with remarkable regularity throughout the length of the tank. These finer particles constitute, in the aggregate, the greater portion of the solids within the tank in the course of its ordinary and normal operation.

Now, the solids which become attached to the top and bottom of the tank are retained and subjected to gradual dissolution until only their refractory constituents remain. They are, therefore, safely disposed of so far as passing out of the tank is concerned, but the larger portion of finely suspended particles, which fill the body of the liquid, and which constitute by far the greatest portion of organic solids within the tank, are not cornered, so to speak, in any such manner. To all practical intents and purposes, they are identical for the time being with the liquid, and rest or flow with it, as the case may be. Vast quantities of the finer particles are undergoing the final stage of dissolution and disappear as solids, while large quantities of the more refractory matter pass off at the outlet of the tank to encumber the secondary stages of purification.

Theoretically, we should retain all these floating particles within

the tank until they are dissolved. Practically, we cannot do so. If we attempt to intercept them with screens, such screens are at once heavily clogged, or we are involved in a large amount of manual labor and expense for cleaning. If we extend the length of time during which the body of the liquid with its contained matter is retained within the tank, we produce the disappearance of the suspended particles only by the increase of serious drawbacks in the production of toxins which interfere with septic action, and refractory effluents which are difficult to purify by secondary processes. Mr. Alvord.

To shorten the time of rest within the tank is ordinarily to increase the outflow of solids, not only in the finely divided state, but with a certain percentage of coarser particles. In cold weather, we shall find the aggregate number of particles increased, due to their slower dissolution, and in summer the number may diminish, owing to the more rapid action of high temperatures. Each change in the initial sewage, whether of volume or strength or temperature, will cause a change in their relative number and appearance in the overflow.

No one who has thoughtfully watched a full-sized septic tank at work month after month and year by year, and has carefully noted these variations can conclude otherwise than that there is an important relation between the capacity of the tank and the rate of flow, which is susceptible at least of some regulation. It is quite true that it is only a rough kind of regulation of the broadest and most general kind, nevertheless, the lack of uniformity in volume of flow, variations in strength of sewage, and fluctuations from temperature are very great in most plants under actual working conditions, and call for a reasonable adjustment of the period occupied by the flow of sewage through the tank, so that the happy mean is obtained where suspended matter in the outflow is at a minimum consistent with an easily oxidized effluent.

Early experiments by the writer on one of his first and most unsuccessful tanks demonstrated beyond a doubt that such regulation was both possible and desirable, and some account of these experiments and their results have been published elsewhere.*

Finally the writer would endeavor to follow out the general thought in Mr. Fuller's paper by crystallizing what, in his opinion, are safe conclusions of recent origin, and known facts which have been well demonstrated at this time in rapid sewage purification.

In General.

1. The nature and quality of sewage is exceedingly complex and variable so that a special study of the local conditions is always advisable.

* *Journal* of the Western Society of Engineers, April, 1902.

Mr. Alvord.

2. No well-designed and properly operated sewage plant should result in a nuisance to its neighborhood, but, nevertheless, respect should be shown to the sentiment of property owners in selecting a location, well removed from residence districts.

3. No form of sewage plant, in which large quantities of sludge must be handled by manual labor or mechanical methods, can be said to be necessary or satisfactory.

4. All forms of sewage purification are greatly retarded by the cold of winter, and accelerated by the heat of summer, and due allowance for this drawback must be made in designating the capacity and arrangement of such plants.

5. The function of sewage purification is at times only to avoid a nuisance, while at other times it is necessary to remove a serious menace to the public health. Such plants, therefore, must be designed so that their effluents meet the conditions of their future destination, and local conditions will be found to vary in purity requisite within very wide limits.

6. Where stream flow is available for final disposition and such streams are not used for water supplies, it is nearly always allowable to consider dilution as a final stage of purification; care being taken that the proportion of impurity allowed to enter the stream is not greater than can be successfully dealt with by the dry-weather flow without resulting nuisance.

7. Chemical and bacterial analyses in sewage purification works are quite apt to be misleading, unless taken in considerable numbers over extended periods and under all conditions.

8. The designer of a sewage plant should have the opportunity to direct its operation for at least one year after it is put into service, in order that he may train intelligently its future care-takers and see that the ideas which he incorporated into its design are thoroughly carried out in operation.

9. The theory of sewage purification is in advance of the practice, and at present not so much can be learned from experimental work, unless conducted upon a very large scale, as can be derived from studies of the numerous full-sized installations now in operation.

10. The problem of sewage purification naturally divides itself into two stages, the first of which consists in dealing with the suspended matter, and the second of purifying the clarified liquid.

11. The greatest single problem in sewage purification is to deal successfully with suspended matter.

12. While very great advances have been made in reducing this difficulty in the last few years, and while it is now within much more manageable and economical limits than ever before, the problem is not yet fully and satisfactorily solved.

13. After the elimination of all or the larger portion of the suspended matter has been successfully accomplished as a first stage, there are no inherent difficulties in properly purifying the liquid, thus clarified, with economy and efficiency. Mr. Alvord.

14. Suspended matters are best dealt with without attempting mechanical or chemical separation from the liquid vehicle.

15. The screening, sedimentation, roughing filters, coarse contact beds, and septic tanks all form more or less practicable methods of dealing with suspended matter, when preliminary separation is not attempted.

16. Sufficient data do not yet exist to determine the proper arrangement, necessary regulation, and comparative economy of these different methods, and the largest portion of that which is now uncertain in sewage purification is due to this cause.

17. So far as it is possible to judge at this time, the septic tank appears to be in the lead in the matter of dealing with the solids of sewage. It would seem that comparatively little attention is being given to other methods just at this time.

Septic Tanks.

18. Under present designs and methods of operation, septic tanks do not deal with all the suspended matter in sewage, but a residue remains in the tank, which must be removed from time to time, and some passes out of the tank in the overflow under average conditions. Evidence shows that this residue varies greatly under different conditions, but, on the average, it is very much less in amount compared with the suspended matter in the original sewage, so that large economies are effected not only in the primary stage of getting rid of the suspended matter, but also in the secondary stage of filtering the clarified liquid.

19. A desirable effluent from the septic process should be largely free from suspended matter, but not in a state of advanced decomposition. The effective mean is reached when such effluent admits of good nitrification by rapid filtration at high rates of flow without clogging the filters with suspended matter at the same time.

Coarse Contact Beds and Roughing Filters.

20. Such beds receiving raw sewage are only successfully worked with extensive mechanical screening and the prior interception of all mineral matter.

21. While such beds lose in effective capacity, the length of time of effective operation prior to renewal is still so long that the complete cleaning of the contact material, or possibly its renewal,

Mr. Alvord. properly falls under the head of operating expense, and with more careful study effective arrangements for cleaning may not become unduly expensive.

22. Coarse contact beds and roughing filters properly designed and well regulated will deal successfully with a large percentage of the initial suspended matter in sewage, but the results accomplished with them so far do not seem to equal the results from the septic tanks.

23. Contact beds and roughing filters require for their operation a considerable amount of fall, the same is not the case with septic tanks and gives the latter great practical advantages.

Secondary Treatment.

24. The secondary treatment of sewage, by which is meant dealing with a clarified liquid containing impurities in solution, has been extensively studied and is well understood at this time. It presents no difficulties which are not easily and economically overcome.

25. All secondary treatments, however, become complicated when they have to deal with the indifferent removal of suspended matter in the primary stage, and this is the most frequent cause of failure in the secondary treatment of sewage.

26. In the present state of the art, it is necessary to estimate upon secondary treatments which will, at least, deal with a small proportion of the more finely divided suspended matter which escapes from the primary treatment.

27. The most available forms of secondary treatment at the present time are intermittent filtration through sand beds, fine-grained contact beds, intermittent continuous filtering and broad irrigation.

Intermittent Filtration.

28. Where porous soils exist in abundance, and land is comparatively inexpensive, intermittent filtration through sand is the most desirable process now available to accomplish the second stage of purification.

29. In intermittent filtration, rates of 250 000 to 400 000 gal. per acre per day are practicable when dealing with sewage from which the suspended matters have been largely removed.

30. The effective size of the sand grain in relation to the dose is of the utmost importance, and coarse sand in intermittent filtration effects great economies by increasing the allowable rates of flow without seriously reducing the purity of the effluent. Such increased rates of flow, of course, always decrease the necessary area of beds required and proportionately the first cost of the plant.

31. The effectiveness of intermittent filtration is seriously re-

tarded in cold weather in northern climates, and due allowances should be made by an increased area when designing plants for such climates. Mr. Alvord.

32. A well-designed and properly regulated intermittent filtration field will produce a higher degree of purity and less variation in the purity than any other method now available for the secondary stage of purification.

Contact Beds.

33. In localities where land is expensive or porous land entirely unavailable, contact beds offer an alternative to intermittent filtration for the secondary stage. Such beds require a minimum amount of land, but a maximum amount of fall.

34. The expense of the contact-bed system is such that, in localities where a good site can be obtained, it is often more desirable to construct intermittent filtration beds from material brought from a distance rather than to resort to contact beds.

35. The chief difficulties in the contact system are the necessity of having considerable fall, the expense of obtaining tight tanks of large size, and the necessity for a stable contact material.

36. Contact beds, in which the size of the material is suitable for the amount of suspended matter received in the sewage, do not ordinarily fill up or clog too fast, but renewal of the material or its cleaning at long intervals may be a reasonable operating expense.

37. A stable contact material is more desirable than one of higher bacterial efficiency, as ordinarily the bacterial efficiency of available materials does not differ seriously.

38. The effluent from contact beds, properly designed and well operated, is satisfactory for all ordinary installations.

Automatic Rotating Appliances.

39. Good and reliable automatic appliances are now on the market, by which the sewage may be mechanically rotated upon intermittent filtration beds or may fill and empty contact beds to the great advantage of the plant in economy of operation and regularity and uniformity of flow.

40. Automatic devices should not displace intelligent supervision and some labor in the form of care-taking.

Intermittent Continuous Filters.

41. Intermittent continuous filters have now been in successful operation as full-sized plants under ordinary working conditions long enough to establish their claim to careful consideration in new installations.

42. Like contact beds they need a minimum of land, but a maximum of fall. It is apparently safe to estimate upon rates of

Mr. Alvord. flow of 1 000 000 to 1 500 000 gal. per acre per day with ordinary domestic sewage fairly well clarified of suspended matter.

43. Like contact beds, the stability of the filter material is of more importance than its high bacterial efficiency.

44. With any considerable quantity of suspended matter carried over from the primary stages of purification, the problem of a proper and effective distribution system is a serious one and in large installations very difficult and expensive both in first cost and economical operation.

45. The problem of clogging of the beds of intermittent filters with suspended matter is analagous to the similar problem with contact beds, but there are indications that the continuous intermittent filter, properly designed and operated, will receive suspended matter for a longer time with less reduction of voids than the contact-bed system.

46. The problem of freezing weather in the northern parts of this country, at first thought to be a serious objection, is apparently overcome by simple covering which is not unduly expensive.

There are many unsolved problems in sewage purification still remaining for consideration. We have had many ingenious theories as to the precise mode of action of bacteria in breaking down organic matter, but it is probably only safe to say at the present time that in some way unknown to us minute organisms are capable of breaking down organic matter under certain conditions of suitable environment, which have been and are being developed from experience.

We cannot draw any sharp line between anaerobic and aerobic action. We cannot trace nitrification to any one form of bacteria with any certainty, and we do not know the precise function of facultated bacteria, or what part enzymes have in organic dissolution

We are groping after some method of retaining suspended matter in septic tanks until it shall be wholly dissolved and at the same time not render the effluent refractory.

We want to know if a so-called anaerobic filter will accomplish this, that is to say, if a continuation of the septic tank, which could be filled with coarse material, might mechanically arrest the finer particles of suspended matter. If this is possible, at what rate is it safe to operate such a contrivance? Will it have to be cleaned? If so, how often? Shall we operate it under aerobic or anaerobic conditions?

We would like to know what other methods might be devised to complete the work of the primary stage in eliminating suspended matter. Is it best accomplished by some screening device preceding the septic tank, or a filtering device following?

Mr. Alvord.

We would like to know how to operate the septic tank. Shall we find some fixed time which is good enough for all classes of sewage under all temperatures, or shall we introduce methods by which the flow can be controlled and regulated?

What shall we do with the proportion of sludge retained by the septic tank, and in what way can it be best removed, and what disposal should be made of it? When is a septic tank not a septic tank, but a sedimentation tank? And what is its best form? And when should it be covered, and when is it best to leave it uncovered?

If suspended matter must be carried over from the primary stage of sewage purification to the secondary stage, how much can we profitably deal with?

How long will contact beds run with fine suspended matter coming over upon them, and what will be the cost per million gallons to keep them in condition?

How much suspended matter will intermittent continuous filters take and for how long? And where is the balance between employing labor to keep a cheap distribution system open and a more costly device which will keep itself open?

These are some of the questions which engineers are asking themselves when engaged upon studies for new plants. We have all the theories as to what the answers ought to be, and we have answers based only on general experience; but such theories and answers are very much in need of new light.

Mr. Barbour.

F. A. Barbour, M. Am. Soc. C. E., Boston, Mass. (By letter.)— Mr. Fuller has covered the subject of sewage disposal so well that it is difficult to add anything of value.

Perhaps the most marked feature of American practice has been the use of intermittent filtration at low rates through sand. The scientific development of this method of purification may be said to date from the classic experiments of the Massachusetts State Board of Health. Its value has been amply confirmed by numerous plants in New England and other parts of the United States, and, in the light of present knowledge, it may be said that, wherever economically possible, this method is the most easily operated and most reliable for the ordinary municipality.

In its best American development, intermittent filtration through sand is apparently not appreciated in England. This is presumably because of the difficulty of obtaining suitable sands—a fact which also accounts for the genesis of so many schemes of high-rate purification and the exploitation of proprietary claims on these methods.

High rates are an attractive possibility, but, in the opinion of the writer, only justifiable where sand filters operated at low rates cannot be constructed because of the cost, or in the case of very large plants where it is desirable to limit the total area, and where a

Mr. Barbour. well organized and equipped staff will guarantee scientific management.

In this latter case, it may be proved feasible to operate at rates of 1 000 000 gal. per day per acre or higher, to maintain this rate in winter by roofing the filters and at intervals by removing and washing the surface layer, to aerate by compressed air and to burn the sludge or intercepted solids in crematories, but few engineers in this country have, as yet, had an opportunity of considering such a problem. To the engineer who has had the experience of constructing what he believed to be a well-designed plant and, on coming back several months later, finding the plant neglected and practically a failure because of inadequate attention, the value of a method requiring for success little knowledge or skill is forcibly brought home.

In considering the relative value of different methods, it is necessary to take into account the conditions under which most plants are operated. What is most needed at the present time is an appreciation on the part of civic authorities of the fact that a sewage disposal plant demands, for its success, more or less study and attention. If it were the custom for the designer to be retained to operate the plant until a routine of management could be established, many schemes of disposal, not feasible under present conditions, would be successful.

Sand filters operating at low rates require relatively little attention; the effect of improper handling is confined largely to the surface and can be corrected readily, and the quality of the filter is less intimately dependent on its handling than in those working at higher rates. The necessary elements of success in intermittent filtration are the obtaining of a sand of suitable "effective size," uniformity of grain, and free from organic matter; the division of the field into beds of an area which will make possible the maintaining of effective intermittency; and the application of the sewage in doses of such size and at such a rate that it will be evenly distributed.

The maximum rate possible by this method has not been finally demonstrated either for raw or treated sewage. It is intimately dependent upon the scheme of dosing, and this in turn must be adapted to the temperature variation and the depth of the filter. Experience at Saratoga has proved that a method of dosing suitable for summer must be modified to meet the extreme conditions of winter, and it is questionable whether sprinklers, revolving arms, or the movable spraying apparatus, which have been so much exploited during the past few years in England, are feasible in the northern half of the United States, unless the filters are roofed.

In such experimental work as has been done, but little attention

has been paid to the methods of dosing, and from the small scale of these investigations it is perhaps impossible to obtain results which would be reliable in practice. It is unquestionably true that higher rates can be maintained, with the same degree of purification, by applying the sewage in small doses at frequent intervals than if the entire daily amount is flowed on the filter at one time, and experimental studies to determine the maximum rate and efficiency possible by a scheme of dosing suitable to the climatic conditions of the United States would be of value at the present time. Mr. Barbour.

The maximum rate in practical design is that possible at the time of lowest temperature. It is dependent on the physical condition of the surface layer in winter. Sewage, even after preliminary settling, contains a considerable amount of fine inorganic matter which lodges in the upper layer of the filter and gradually reduces the "effective size" of this layer. It is, therefore, true, that experimental work carried on for a limited period will not demonstrate the rate which should be made the basis of design. About double the area necessary for summer is required for winter maintenance of filters in New England after they have been in use for a number of years.

The minimum depth of filter which can safely be adopted is an important consideration where sand in natural position cannot be found. In the Middle West, sand filters usually cost from $2 000 to $2 500 per acre per ft. in depth. Experimental work to prove the comparative value of different depths of filters operated at different rates and dosed with due regard to the depth would be of great value.

Experience has apparently proved the advisability of separating the heavier solids from the sewage before applying the liquid to sand filters. This may be effected by sedimentation, septic treatment, or rapid strainers. Any of these methods may be used as the final process of purification, depending upon the quality of effluent which local conditions make it necessary to obtain, but in the majority of cases these methods will, in this country, serve as a preliminary treatment to final purification by sand filters.

In Massachusetts, the authorities, who have been so largely responsible for the trend of American practice in the past, frown on the use of high-rate methods—refusing to sanction the use of the septic process even as a preliminary treatment and practically insisting on sand filtration as the final means of purification. This is presumably because of the cheapness with which suitable sands can be usually obtained in sufficient areas to make any elaborate preliminary treatment unnecessary, but it is also due to the insistence on a standard of purification which cannot, except at great cost, be maintained in other parts of the country. In the Middle West, if

Mr. Barbour. sanitary progress is to be made, effluent standards, rationally adapted to the local conditions and the cost of the work, will have to be accepted.

The septic process, while not fulfilling the earlier claims made for it as a final solution of the sludge problem, has clearly proved its right to exist. At a number of plants designed by the writer, this method has been in use for several years with a marked reduction in the cost of maintaining the surface of the filters and an increase in the possible rate of filtration during the periods of low temperature.

Whether the septic effluent, because of the anaerobic decomposition of the organic contents of the sewage, can be purified at higher rates than sewage from which the same percentage of solids has been removed by sedimentation or straining, is a doubtful question. The relative value of these processes will probably rest on their economical effect in the handling of the sludge.

The efficiency of the septic process depends on temperature, and for this reason, as well as for the better appearance and lessened probability of odors, it is advisable, in the opinion of the writer, to roof the tanks. Experimental work to determine the relative efficiency of open and closed tanks in periods of low temperature would be interesting. At Saratoga, in the winter of 1903-04, the scum froze to a depth of 4 in. under the concrete groined roof covered with 18 in. of soil; what would have happened if the tanks had been uncovered is a question worth considering.

The effective liquefaction of the solids is confined to the portion of the tank below the lower surface of the scum and does not extend into this scum more than a few inches. It is, therefore, desirable to distribute the solids as uniformly over the area of the tank as possible and to design the inlet and the tank so as to effect this result.

The depth should be sufficient to permit the seasonal variation in the amount of accumulated solids without affecting the efficiency of the tanks. At one plant operated under the supervision of the writer, the solids, as measured by a Fowler gauge, in April, 1904, occupied 45% of the total space, but, with the rising temperature and increased bacterial activity, the abnormal accumulation disappeared before July 1st.

Aeration of the septic effluent is believed to be an important factor in its successful purification by filtration. In the opinion of the writer, the difficulty in purifying a very stale effluent, which has been met in some cases, might have been overcome by adequate aeration.

Contact beds have been used with more or less success at a number of places in the United States. The claim that, because of the

coarser material used, the effective zone of bacterial activity extends deeper than in sand filters carries with it the corollary that solids may accumulate below the surface, gradually reducing the air space and necessitating the removal and replacing of the bed material. Experience has, therefore, naturally indicated the advisability of removing the larger portion of the solids from the sewage before applying it to contact beds. Where this method is used with a combined system of sewers, the flow in time of storm should be diverted, as the silt and clay then carried rapidly reduces the available air space of the beds. Mr. Barbour.

The elements of success in contact-bed work appear to be the obtaining of a material which will not disintegrate, varying in size of particle only between certain narrow limits. As a final method of treatment, contact beds are only economically possible where the degree of purification can be adjusted to the varying stream conditions.

The problem in the use of streaming filters in the northern half of the United States will be in devising methods of distribution, which can be operated during cold weather. If the rate can be made high enough to justify economically the roofing of the filters, the problem will be solved.

It is probable that, in the future, plain sedimentation, strainers and streaming filters will all be used as preliminary treatments to a greater extent than in the past, but all these methods demand more constant and careful attention than the septic process.

To the engineer contemplating the adoption of these high-rate methods, the question of proprietary rights is important. If the patents, as issued, were valid, it would be a difficult matter to avoid the infringement of some process or combination whatever the method adopted. It is probable, however, that few of the patents are valid. Certainly a study of some of the file wrappers and references to interferences made by the Government examiner would indicate that, had he been better acquainted with the literature of sewage disposal, these patents would never have been issued.

George W. Fuller, M. Am. Soc. C. E., New York City. (By letter.)—The writer is gratified at the fullness of the discussion on this paper covering the present status of sewage disposal in the United States, with an outline of progress during the past decade. These discussions and the paper by M. Bechmann set forth clearly the general practice in France, England and Australia, and record the experiences of engineers dealing with various conditions both in this country and abroad. The differences of opinion seem to be no greater than might be reasonably expected on a subject which is influenced so materially by local factors. Mr. Fuller.

Of the various aspects of sewage disposal in the United States,

Mr. Fuller. there is no feature which has attracted more attention than the one mentioned by Mr. Coane, *viz.*, that sewage disposal by dilution is so generally practiced here, and that there are so few artificial purification works. As stated by Mr. Hering, this is due, not only to the sparsity of population and relatively large drainage areas of the watercourses, but also to the fact that in a large section of the United States there are much greater rainfalls and stream flows than prevail in England and other countries. When consideration is given to the population in this country, located on the seacoast and along large rivers, as compared with the population on the relatively small watercourses, and also to the more favorable conditions for the dilution method, as just stated, it is seen that, so far as prevention of nuisances is concerned, the United States occupies no such backward position in sewage disposal as many engineers elsewhere might suppose.

In New England and in the northeastern section of this country, where the population is quite densely distributed on the small watercourses, it is probable that sewage purification plants of artificial construction, where needed to prevent nuisances, are about as numerous (and quite likely more so) as they would be under the custom prevailing in any country, with the possible exception of England.

If we disregard the question of infection of large rivers used as a source of water supply, the communities now in urgent need of purification plants of artificial construction do not, by any means, form a large percentage of the total urban population of the United States, notwithstanding that such works are greatly needed in some places.

As to the different observations relative to the behavior of sewage in salt water and in fresh water, as noted by Mr. Fowler, it is probable that a full record of experiences and investigations here and abroad would show no radical differences. The statements made in the paper were based upon detailed investigations by Mr. H. W. Clark, as summarized by J. R. Freeman, M. Am. Soc. C. E.*

Oyster pollution, as mentioned by Dr. Rideal and Mr. Hooper, has unquestionably received a large amount of attention in England recently, as shown in the Fourth Report of the Royal Commission on Sewage Disposal. Investigations, seemingly corresponding in general thoroughness, have been made in the United States, although as yet few of the results have been published, especially in the case of the Massachusetts State Board of Health. The attitude on oyster pollution, as stated by Mr. Hering, seems to be the logical one, *viz.*, of considering the relative importance and practicability of the oyster layings and of the purification of the sewage. Where

* Report of the Charles River Committee, 1903, p. 45.

the oyster layings are a large and important industry, it seems to be judicious to purify the sewage rather than drive the oyster business from the locality. On the other hand, if the oyster industry in a certain section is relatively small as compared with the cost of a purification plant required for the hygienic purification of the sewage of the community, then it seems reasonable to have the oyster layings transferred to other sections. Mr. Fuller.

M. Bechmann's paper describing sewage disposal conditions in France during the past 10 years forms an interesting statement of the application of irrigation methods on a large scale. It further shows an appreciation of the merits and practicability of more recent biological processes, which is closely in alignment with the views held by those who have considered the matter most in the United States. The Paris works for the disposal of sewage by irrigation do not yield a revenue sufficient to meet the operating expenses and the interest charges on the investment, and as the metropolitan district of Paris increases in size, it is quite natural that the authorities should endeavor to lessen expenses by the use of more rapid methods, especially at times of harvesting, when these methods would serve a valuable purpose as "regulators" to maintain the regimen of the plant without injury to crops.

Irrigation at Melbourne, Australia, which is very fully described by Mr. Thwaites, forms the only important case within the writer's knowledge where the income from sewage irrigation works has equalled ordinary interest rates on the cost of purchase and preparation of the land required. As Mr. Thwaites points out, however, the financial year, 1902-03, in which they realized a net profit above operating expenses and interest charges, was an exceptional one. due to droughts, and their normal revenue can hardly be expected to equal their interest charges and operating expenses.

Sewage irrigation in the United States, as stated, is hardly practicable in the Eastern States, where the rainfall is high during the cropping season, and, in the West, as pointed out by Mr. Leighton, it is merely an incidental feature to the efforts made in the arid and semi-arid regions to secure water for agricultural pursuits.

The most distinctive feature in present American practice in sewage purification is the wide use of intermittent sand filters throughout the glacial drift area, where porous sand and gravel layers are available at low cost, as discussed by Mr. Baker and several others. The method, as stated by Mr. Barbour, does not seem to be well understood abroad, especially in England, where such areas of porous sand at low cost are not available, and where, in general, the conditions resemble much more closely those in the South and Middle West of this country. The reasons for this will doubtless be better appreciated after a careful perusal of the excel-

Mr. Fuller. lent report for 1903 of the Massachusetts State Board of Health on the various disposal plants in that state, which has appeared since this paper was prepared. It is not to be forgotten that intermittent sand filters in the United States are generally capable of disposing of the raw sewage of 800 to 1 200 persons per acre as compared with the 100 to 150 per acre on the irrigation fields abroad. Comparatively speaking, there is no doubt about intermittent sand filters producing a more thoroughly purified effluent than any of the more recent biological processes, so-called, involving septic treatment and filtration through coarse-grained beds. Under some conditions, intermittent sand filtration for sewage purification would no doubt be preferable to the use of the more recent methods, even if the latter should be somewhat cheaper.

Throughout a large section of the United States, as in England, intermittent sand filters, through the lack of available material at a reasonable price, are not directly applicable. The dividing line between the conditions favoring intermittent filters and those favoring septic tanks, coarse-grained filters, etc., can hardly be told at this time, as it involves too many local factors affecting costs, especially those of operation. These features, while still fragmentary, as pointed out by Mr. Alvord, are beginning to assume tangible form, and it will probably not be long before this evidence will be far more crystallized than at present. While it is true, as Mr. Alvord states, that there have been no fundamental changes as to methods in this country during the past five years, there has certainly been a marked advance in the accumulation of valuable data under American conditions.

The idea of using intermittent filtration at low rates, as stated by Mr. Hazen, on rather impervious soil during periods of low stream flows doubtless has much merit for some localities.

Mr. Hooper's clear statements of the requirements of the Local Government Board, as to rates of filtration, provisions of storm flow, etc., are very valuable in showing the present basis of designing English sewage works.

As to the nature of the septic treatment, the writer feels very certain that Mr. Alvord's views regarding the influence of different periods of flow through the septic tank, relate to conditions which must be regarded as exceptional rather than general. There is much organic matter in sewage which unquestionably deposits in a septic tank, as will be shown in the forthcoming report upon the results accomplished at the Columbus Testing Station on the purification of about 300 000 gal. of sewage daily by different procedures operated side by side under different known conditions. Speaking generally, the omission from various investigations, up to within a few years ago, of the determination of suspended matters in sewage before and after treatment has led to somewhat questionable

theories, the correction of which requires complete data on suspended matter, as was the case in earlier years in the development of methods for the treatment of muddy river waters. Mr. Fuller.

A very important question touched upon in several of the discussions is the treatment of suspended matters which clog filters, and upon this much light is thrown by such data as mentioned above. Dr. Fowler mentions a significant point in this direction, *viz.*, the precipitation by oxidation (within filters and elsewhere) of matters previously in soluble form.

Under some American conditions at least, as pointed out by Mr. Ogden, there is very little or no reason for doubting that the septic treatment can be successfully used in relatively smaller tanks than is the case abroad. This seems to be largely due to the much smaller proportion of suspended matters which are deposited from the weaker American sewages, and facilities for the accumulation of which, especially during the colder portion of the year, must be provided.

At Saratoga the cover for the septic tank is no doubt helpful during the severe winter weather, as described by Mr. Barbour. Under many, if not most, conditions, however, it is probable that the covers are not helpful to a degree commensurate with their cost.

Mr. Alvord's statements strengthen the growing belief that well-designed septic tanks may operate for several years with domestic sewage without the removal of any sludge. This is not in conflict with statements that sewages containing street wastes and trade wastes require quite frequent cleaning of septic tanks, due largely to the suspended mineral matter entering the tanks.

It is evident that opinion differs as to the presence of odors about septic tanks. This is obviously due to differences in conditions, both in the sewage itself and in those for the septic treatment. Generally speaking, with ordinary sewages the odors may be reduced to a point where they are not seriously objectionable.

No doubt there are various conditions where double contact beds are preferable to single contact beds. In making the statements contained in his paper, the writer had in mind that single contact beds properly operated could prepare an effluent so that it would be non-putrescible. A secondary contact, as preferred by Dr. Fowler, would no doubt improve such an effluent, but the writer is of the general opinion that if a higher degree of hygienic purification were desired, it would be preferable to follow methods more comparable with those which are used in purifying a highly polluted water rather than to use a secondary contact treatment.

Owing to the well-recognized differences in the strength of sewages in the United States and abroad, it is to be noted that it is hardly feasible here to secure such high percentages of purification as cited by Mr. Killon for certain English methods. Percentages

Mr. Fuller. of purification are of value in making comparisons, but attention should also be paid to the composition of the effluent.

How far it is desirable, under various conditions, to purify sewage beyond the point where a non-putrescible effluent is obtained, is still an open question; but it is well worth considering, as Dr. Rideal suggests, that copper sulphate and other chemical means of sterilization may be made available for effluents of rapid-rate filters, thus securing, if desired, a bacterial removal equal to or better than that accomplished by well-known intermittent filters.

Sprinkling filters seem, on the whole, to be preferred to contact beds by the gentlemen discussing this paper, and much of the recent evidence seems to be pointing in that direction. To those who visited the Columbus Testing Station during the unusually cold winter of 1904-05, there is no more interesting feature than the satisfactory behavior of well-designed sprinklers when the temperatures of the air are far below the freezing point. To be sure, more or less frozen sewage accumulates upon the beds, but during ordinary cold periods this does not seem to be seriously objectionable. By arranging the piping system so that during excessively cold weather the sprinklers may be thrown out of service, and the filters operated temporarily as contact beds, there seems to be very little doubt about this type of filter being able to give satisfactory service during the winter months, even in the northern portion of the United States. This being so, the economical advantages of rapid-rate filters as compared with intermittent filters will take a different form from that generally considered hitherto.

As to strainers for the purpose of removing suspended matter to prevent clogging at the surface of filters, while the evidence on the whole does not now seem to be encouraging, it is by no means certain that new phases will not later put the matter on a more favorable basis. It is certainly of interest to note the statement in M. Bechmann's paper that an automatically operated mechanical filter of the Wilson type is now being considered as a strainer at Paris.

Future successes and failures with sewage purification projects in the United States will depend more upon adequate management of the works than upon adequate design and construction by engineers familiar with the current evidence upon this subject. The writer is thoroughly in accord with the views of Messrs. Rosewater, Alvord and Barbour as to the necessity of competent supervision of plants, especially during the first year of their service. This has been the practice in a number of instances in connection with water purification plants, and it has no doubt contributed materially to the rapid advance made during the past decade in that branch of Engineering. There is no reason to believe that equally satisfactory results will not follow in sewage purification.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISPOSAL OF MUNICIPAL REFUSE.

Congress Paper No. 66.

REVIEW OF GENERAL PRACTICE.

By Rudolph Hering, M. Am. Soc. C. E., New York City, U. S. A.

Congress Paper No. 67.

NOTE ON THE REMOVAL AND UTILIZATION OF MUNICIPAL REFUSE IN FRENCH CITIES.

By P. Tur, L'Ingénieur en Chef adjoint du Service Technique, de la Voie Publique et de l'Éclairage de la Ville de Paris, Paris, France.

Discussion of the Subject by

W. Francis Goodrich, London, England.
M. N. Baker, New York City, U. S. A.
Shirley C. Hulse, Ithaca, N. Y., U. S. A.
Andrew Rosewater, Omaha, Nebr., U. S. A.
Robert Spurr Weston, Boston, Mass., U. S. A.
George W. Fuller, New York City, U. S. A.

Gardner S. Williams, Ann Arbor, Mich., U. S. A.
L. J. Le Conte, Oakland, Cal., U. S. A.
J. C. H. Stut, San Francisco, Cal., U. S. A.
Ed. Vermehren, Hamburg, Germany.
Messrs. Bohm and Grohn, Berlin, Germany.
G. Watson, Leeds, England.
Rudolph Hering, New York City, U. S. A.
P. Tur, Paris, France.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject

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Paper No. 66.

DISPOSAL OF MUNICIPAL REFUSE.

REVIEW OF GENERAL PRACTICE.

By Rudolph Hering, M. Am. Soc. C. E.

The art of collecting and finally disposing of the miscellaneous solid city refuse not capable of removal by water carriage in sewers but requiring special cartage, is perhaps the latest addition to the various branches of municipal engineering.

The older cities of Europe have already fairly met this new problem which modern city life has forced upon us, and have partly solved it. But the relatively new conditions surrounding American cities, the different social habits as well as natural and commercial environments, the comparatively uncertain character and speed of their development, and, especially, the frequent changes in city government, have tended to delay the development of many of the municipal public works in the United States.

The proper removal of solid waste materials or refuse has received less attention than other works because its sanitary and financial aspects were least important. Within the last few years, however, it has been brought somewhat into the foreground, chiefly in the larger cities, for the purposes of preventing nuisances and inconveniences rather than as a health measure.

At first no class of professional men were known in the United States to be engaged in advising as to the best solutions for these new problems. Presently, however, there appeared men of business who sought to sell furnaces for destroying the obnoxious combustible refuse, and these were followed by companies who sought profit in the utilization of some of the wastes. In but a few instances did city officials take the initiative in devising proper methods of disposal; hardly one American city can be found where exhaustive preliminary investigations were made and where the solutions suggested and practised have been as yet entirely satisfactory and final.

It has happened repeatedly, after a supposed solution had been unsuccessfully attempted, that some new method, backed financially by influential parties, was suggested, and the strongest claims made that it would overcome all the troubles of former methods; yet, after a few years' trial this "new method" also was found wanting, either in allowing some one of the related nuisances to persist, or in requiring too large an expenditure of money to prevent the same.

The time seems to be near when, in the United States, also, the subject bids fair to receive treatment along scientific lines, similar to those pursued in other branches of engineering, and when the particular conditions of each city can be brought to indicate definitely, not only the best but also the cheapest method of dealing with the class of materials under consideration.

The problem as presented to-day is to effect a sanitary collection and disposal of city refuse at the least cost; the word sanitary in this case meaning the prevention of all nuisances and of such evils as may result from the potency of some classes of refuse to be a medium for disseminating disease.

It is the purpose of this paper to outline what the writer believes to be the proper method of procedure for the solution of this question.

For the purpose of discussion it will be found most convenient to separate the subject into its natural parts, so that each one may be taken up separately and studied intelligently with reference to the rest; thus pointing to the most efficient treatment of the entire refuse in a given case. Accordingly, there will be considered, first, the refuse materials themselves, then the methods of collection and disposal, and, finally, the cost.

Materials.

Municipal refuse may be divided into four classes: Ashes, garbage, street sweepings and rubbish.

It is not intended here to include as a separate class either dead animals which fall to the care of the public, or night soil which in many cases requires a special removal from premises.

In the case of dead animals, it is expected that they are either utilized for profit, burned, or buried. If the community is sufficiently large, there may be some private concern ready to utilize, for profit, the available grease, hides, bones, etc., and this industry, if subjected to proper regulations against creating a nuisance, can be left to do this work. Where such an industry does not exist, but where there is a crematory or reduction work for disposing of the garbage, the dead animals can be treated together with this garbage. In the absence of either opportunity, burial is the only other proper disposition.

Similar remarks apply to the night soil. Its treatment generally consists in a transformation into compost, or in directly spreading it upon land as manure. Where this is not done, it has been mixed with and treated with the garbage, or towed out to sea.

In many European cities we find a careful account rendered of the quantities of the various parts of municipal refuse, as well as of their analyses. In the United States such information was entirely lacking up to within a very few years, and even now is confined to a very few cities.

Unless otherwise marked, the quantities given in this paper are recorded in weights instead of in bulk. It is quite true that the item of labor varies more nearly with the bulk than with the weight of city refuse, and that some refuse weighs twice as much as some other. But it is impracticable to measure by bulk, and Mr. G. Watson in England suggests the much better method of keeping account by reckoning the cost of labor by tons worked per man per hour instead of by wages per ton.

In dividing the refuse into the above-mentioned classes the following comments are offered:

Ashes.

Ashes comprise the mineral waste left after the combustion of coal. They vary both as to quality and quantity in different com-

munities and even in the same city, with the season, kind of coal used, the purpose for which it is used, and the habits of the people. In the temperate zone much more coal is used in winter than in summer. Anthracite coal leaves almost twice as much ash as bituminous coal. For commercial steaming purposes great care is used to burn the coal thoroughly, with the result that steam ashes contain almost no unburned coal or cinders, while in domestic ashes these constituents are large. An excess of sulphur in the coal tends to form clinkers, which, if cast into a furnace with garbage and rubbish, favors combustion more than fine white ash, which reduces the size of the pores and thereafter the draft.

It is estimated by Craven* from actual examinations that the percentage of unconsumed coal in the ashes of New York City ranges from 20 to 40% of the weight, and he believes a fair average would be 25 per cent.

Ashes from average dwelling houses:	
Coal recoverable	20%
Clinker	15%
Fine ash	50%
Coarse ash and stone	15%
Ashes from large house furnaces:	
Coal	40%
Fine ash	45%
Clinker and coarse ash	15%
Ashes from apartment houses:	
Coal	35%
Fine ash	45%
Clinker and coarse ash	20%

In England, according to Codrington,† the unconsumed coal and cinder in domestic ashes is estimated as constituting about 35% of the ashes.

For Berlin, Bohm and Grohn‡ give the proportion of unconsumed coal in the ashes as only about 3 per cent.

The objectionable part of ashes is the dust, which is apt to

* "Waste Disposal and its Advances," by MacDonough Craven, American Public Health Association, 1899.

† "Destruction of Town Refuse," by Th. Codrington, London, 1888.

‡ "Mullverbrennungs Versuche in Berlin," by Bohm and Grohn, Berlin, 1897.

become a nuisance when the wind is brisk, when the ashes are stored on the sidewalk, carted through streets or being dumped. Ashes may also be objectionable when mixed with other refuse for cremation, because the fine dust interferes with the draft and it generally becomes necessary to screen the material before burning. Ashes are valuable either for the unburned coal which they contain, as a filling material, as an ingredient for mortar, or for road making.

Dawson has given for England the calorific values in British thermal units or units of heat developed per pound, of the following materials with reference to refuse destruction.

Material.	Calorific value.	
	When dry.	With average moisture.
Coal	14 000	9 333
Coke	12 000	8 000
Breeze and cinder	6 000	4 000

Garbage.

Garbage comprises chiefly the food waste, and consists almost entirely of organic matter and water. The main contribution comes from kitchens; but markets, dealers in fresh-food materials, and slaughter-houses supply a fairly good share. This rejected animal and vegetal matter is both solid and liquid in form. Much of it, and particularly the animal matter, readily breaks down and soon becomes foul. The oxygen in the air is not sufficient in quantity, at least during summer heat, to prevent putrefaction from starting within 24 hours, and consequently to prevent the dispersion of offensive odors.

Garbage is the most important part of the city refuse, because it has a greater commercial value than the other parts, due to its containing animal foods and grease, and also because, if not cared for, it is likely to create the greatest nuisance. It has been the subject of more discussion, its treatment has been more varied, and there is more difference of opinion regarding the proper method of treatment, than in the case of any other class of refuse.

The composition of garbage has been ascertained in a few cities, but on account of the differing practises in collection, whether separately or mixed with ashes and rubbish, it is difficult to get exact figures, and rough approximations must, therefore, suffice. The

most important parts to be considered are moisture, grease, animal, vegetal and miscellaneous matter.

Moisture.—In his report upon the New York City wastes, Craven states from official examinations that the average amount of moisture in the kitchen garbage of the larger cities of the United States is about 70 per cent. In the autumn it is greater than this and in winter it is less.

In England, according to Goodrich,* the moisture contained in the entire ash-bin refuse, which includes garbage, ranges from 25 to 35 per cent. Calculation indicates that the moisture in English garbage ranges from 60 to 70 per cent. In Berlin, according to Bohm and Grohn, the moisture in the mixed refuse ranges from 15 to 25 per cent. By a similar computation the moisture in the garbage alone is found to vary from 55 to 65 per cent.

These results indicate, what is known in a general way, that garbage in the United States, by reason of its large amount of fruit and vegetable waste, as compared with that of England and particularly with that of Germany, has the largest amount of moisture, which in some instances has reached 80% and even more.

Grease.—In the report previously referred to, Craven gives the average percentage of grease in kitchen garbage of the larger cities of the United States as about 3%; it varies from 2 to 4 per cent.

In European cities, it is stated† that the percentage of grease varies from 1 to 3%; most of it, however, is nearer the lower figure.

Animal and Vegetal Matter.—According to Craven, the percentage of dry animal and vegetal matter in the kitchen garbage of the larger cities of the United States is about 20 per cent.

According to data furnished by Codrington, the percentage of this ingredient for England can be roughly computed as 24% without the moisture.

Bohm and Grohn found the percentage of animal and vegetal matter, including moisture, to be roughly 80 per cent. Taking, as above, the average moisture at 60% and the average grease at 2%, the average percentage of animal and vegetal matter, including bones, is found to be about 30 per cent.

Rubbish.—Some of the rubbish which naturally accompanies garbage, such as tin cans, berry baskets, bottles and the like, was

* "The Economic Disposal of Towns' Refuse," by W. F. Goodrich, London, 1901.
† Annual Report, American Public Health Association, 1896.

found by Craven to average about 7 per cent. In England a computation gives for this rubbish about 9%, and in Berlin 8 per cent.

The foregoing figures relating to the composition of garbage are shown in Table 1.

TABLE 1.—Average Percentage Composition of Garbage.

Component Parts	United States.	England.	Berlin.
Moisture	70%	65%	60%
Grease	3	2	2
Animal and vegetal	20	24	30
Rubbish	7	9	8
	100	100	100

As before stated, these figures can be taken only as rough approximations. Attention is also called to the fact that they are percentages of the whole, and do not indicate actual quantities, which latter will be given further on.

The table indicates that the proportion of grease to dry animal and vegetal matter varies in the United States, England and Berlin as 0.15 to 0.083 and 0.067. The American garbage is, therefore, the richest in grease, containing after the removal of moisture more than double the quantity found in Berlin, and nearly double that found in England. It is also observed that the proportion of moisture to dried animal and vegetal matter in the United States is 3.5, in England, 2.7, and in Berlin, 2.0.

These facts may explain why the extraction of grease has been found profitable in the United States and not in Europe, and also why, in view of the high degree of moisture contained in the garbage of the former country, cremation has been less successful than abroad.

The objectionable features of garbage are its rapid putrefaction, especially in warm weather, its offensiveness and its suitableness for propagating lower forms of life.

The value of garbage consists in its food and manurial properties, the grease and the combustible matter which it contains. The calorific value of fairly dry garbage has been given as 2 500 B. t. u., when moderately wet as 1 000 B. t. u. These figures have not been verified.

Street Sweepings.

Street sweepings comprise the materials that are collected from the surface of public streets, and consist chiefly of horse droppings and accumulations of general city refuse not otherwise collected, including deposits in catch-basins. It also consists of dust and of earthy material worked to the surface of pervious pavements, of ground-up paving material and mud brought by wheels from country roads.

The composition of this material, therefore, varies chiefly with the quantity and kind of traffic, the kind of pavement and the distance from unpaved roads. Accordingly, it may contain much or little organic matter, some of which may putrefy rapidly, some slowly and some not at all.

The main objection to this material is its fineness, because when it is dust the wind can readily take it up and blow it about, to the discomfort of man and beast and to the injury of food and certain kinds of property. Germs of the most prevalent city disease, tuberculosis, possibly may be abundant in the street, dust, although as yet ground for this belief has not been sustained.

From an inquiry made by the United States Department of Agriculture in 1898* among the cities of the United States, it was found that the average quantity of street sweepings collected annually per 1 000 persons was 168.9 tons. It was also found that most of the material was wasted, and that in general terms about one-fourth of the urban population of the country made an effort to use it for fertilization, amounting to 104.6 tons annually per 1 000 persons.

The quantity of sweepings reported for London is about 150 tons and for Berlin about 125 tons annually per 1 000 persons.

The fertilizing value, being dependent chiefly upon the amount of horse manure, must vary with the amount and kind of traffic, pavements, etc. From asphalt streets in the center of a large city the sweepings will have the greatest value, while from macadamized streets they will have none. In many cities the street sweepings contain much rubbish, which reduces the fertilizing value. In some cities the falling leaves in autumn contribute greatly to the bulk.

Not much useful information has been published on the fertiliz-

*"The Fertilizing Value of Street Sweepings," by Wiley and Ewell, Bulletin No. 55, Division of Chemistry.

ing value of street sweepings, because of the great differences which clearly must exist in the material in different cities, in the same city, and even on the same street. Table 2 gives a general idea of the relation of organic and mineral matter from the central parts of the cities mentioned. It will be seen that the larger the city the greater is the proportion of organic matter, which fact may have its explanation in the relative distances from unpaved streets.

TABLE 2.—Average Percentage Composition of Street Sweepings.

Component Parts.	New York. (Craven.)	Washington. (Wiley.)	Berlin. (Vogel.)	London. (Letheby.)*
Moisture	37	35	39	35
Organic matter	31	20	23	36
Ash	32	45	38	29†
	100	100	100	100
Proportion of organic matter to ash	1 : 1	1 : 2.2	1 : 1.6	1 : 0.8

*In dry weather. †Powdered stone and abraded iron.

The street sweepings of London contain the greatest amount of organic or combustible matter; New York, Berlin and Washington follow in the order named. Most of the organic matter in larger cities will be manure.

Farmers and gardeners generally agree that the fertilizing value of street sweepings is never great, but it is fairly good in cases where the material is well selected from impervious asphalt pavements near the centers of large cities, and where it is judiciously used.

Street sweepings when consisting of little else than manure can be burned, but are of little or no value for steam production.

Rubbish.

Rubbish comprises the miscellaneous refuse which is not specially classed under the three previous headings. It consists chiefly of wood, paper, straw, rags, leather, leaves, stone-ware, glass, metals and sweepings from buildings, and comprises also all trade refuse.

The most objectionable parts of this class of material are the dust and the disease germs which may be brought in cast-off cloth-

ing, bedding and sweepings. Its odor is but slightly offensive and its decomposition is slow and not putrescent.

The value of city rubbish lies partly in what may be picked out, assorted and sold, such as metals, glass, wood, discarded articles of furniture, and partly in the fuel constituents which it contains after such picking. Some trade refuse is combustible and some is not.

The quantity as well as the quality of this rubbish varies greatly with the city from which it is collected, and also with the city districts. It is small in the residence section as compared with the business section, and its character varies with the kind of business.

Table 3 gives some information as to the proportions of different kinds of rubbish collected. It can serve only as a rough estimate when used for comparisons. It will be seen that in New York a large amount of paper and rags is wasted as compared with Europe, a fact which probably holds good for most American cities. The fact that the New York analysis contains no straw and stone-ware is explained by Mr. Craven by the statement that there was but an inappreciable amount of stone-ware in the rubbish, and that although the amount of straw was appreciable, it had never been measured. The large amount of stone-ware in the Berlin rubbish is not explained. That the London rubbish contains no rubber, leather and wood is probably due to the fact that it had been picked out. Some discrepancies in this comparison may be due to a more thorough picking of the refuse in one city than in another, before the published measurements were made. It is reported that the pickings from rubbish in New York City (Manhattan and Bronx) realize about $1 150 per week, but include coal pickings from all ashes collected.

TABLE 3.—Percentage Composition of Rubbish.

Kind of Material.	New York. (Craven.)	London. (Russell.)	Berlin. (Bohm and Grohn.)
Paper	75.0	39.4	23.3
Rags	15.5	3.6	6.3
Rubber	0.1	.....	.....
Leather	1.8	.....	3.8
Straw	.....	29.7	19.7
Wood	1.4	.....	2.2
Metals	3.3	9.2	4.2
Glass	2.9	13.1	7.0
Stone-ware	.....	5.0	33.5
	100.0	100.0	100.0

Dawson gives calorific values in British thermal units for the following materials:

	When dry.	With average moisture.
Bones and offal	8 000	5 333
Rags	5 000	3 333
Paper, straw, fibrous matter and vegetable refuse	3 800	2 500

Combined or Mixed Refuse.

Combining the quantities of the four classes of refuse in a single table, their relative percentages will throw further light upon the subject, although it must again be stated that the different methods of observation make the figures comparable only in a general way. Since neither the amount nor the proportion of street sweepings to other city wastes are often reported, it was necessary to deduce the relation from the best available data. The classification is not the same in all cases. In some, for instance, paper is classed with garbage and dust and dirt with ashes, while in others, both are classed under rubbish.

In Table 4 it appears that the percentage of street sweepings as reported in Boston is small when compared with the other cities. On the other hand, its production of ashes is greatest. Washington has the least proportion of ashes, due no doubt to the absence of manufacturing and to the warmer winter climate. The street cleaning of Washington is more thorough than in most American cities, and compares favorably with that of European cities. Presumably the close correspondence of the figures may be taken to confirm this fact.

TABLE 4.—Percentage Composition of City Refuse.

Component Parts.	New York. (Craven.)	Boston. (O'Shea.)	Washington. (Sutcliffe.)	London.* (Codrington.)	Berlin.† (Bohm and Grohn.)
Ashes	66	70	28	48	31
Garbage	10	16	20	9	19
Street sweepings	18	9	45	40	41
Rubbish	6	3	7	3	9
	100	100	100	100	100

*Computed from analyses of ash-bin refuse reported by Codrington, and a quantity of street sweepings by Ross.

†Computed from analyses of mixed refuse reported by Bohm and Grohn, and a quantity of street sweepings by Baumeister.

By omitting the street sweepings, Tables 5 and 6 can be presented, the first of which includes a few other cities for which data were available. For Montreal summer and winter conditions are given, and it becomes apparent what a great effect the season has upon the quantity of refuse. In winter 60% of the total refuse is classed as ashes, but in summer only 10%; on the other hand, only 25% of the total is garbage in winter, and as much as 65% in summer.

TABLE 5.—Percentage Composition in Weight of City Wastes, excluding Street Sweepings.

Cities.	Ashes.	Garbage.	Rubbish.	Authority.
New York	81	12	7	Craven.
Boston	76	20	4	O'Shea.
Washington	51	36	13	Stutler.
Trenton	75	21	4	Heriug.
Montreal Summer	10	65	25	Pelletier.
Montreal Winter	60	25	15	Pelletier.
London	82	14	4	Codrington.
Berlin	53	32	15	Bohm and Grohn.

From the previous tables it has been possible to prepare Table 7 showing the relative amounts of water, combustible and incombustible matter, for average conditions only.

In Table 7 it is assumed that there is no moisture in ashes or rubbish. The percentage of water thus obtained is at variance with records frequently seen for English cities, and this may be explained by the fact that much of the so-called ash-bin refuse in English furnaces is screened before burning.

Table 7 shows that for the cities mentioned the combustible matter comprises about one-third of the total refuse, the incombustible matter about one-half, and the water about one-sixth during dry weather. If screened refuse is considered and the fine ash is removed, the proportions as given by some English engineers are roughly, one-third moisture, one-third combustible and one-third incombustible matter.

If the percentage of the several parts of this refuse is converted and expressed in actual amounts per 1 000 population per annum, the following tables are obtained partly from the data already mentioned. Table 8 gives the amounts of refuse in four large American cities.

TABLE 6.—Average Percentage Composition of English Refuse. (Classified Approximately.)

Component Parts.	Average English. (Hutton.)	London. (Russell.)	London. (Codrington and Weston. 1886.)
Coal	0.7	0.8	0.2
Coke	0.3		28.9
Breeze and cinder	50.0	63.7	
Ash	12.0		52.5
Dust and dirt	20.0	19.5	
Total ashes, etc.	83.0	84.0	81.6
Vegetables	13.0	4.6	14.0
Paper*		4.3	
Fibrous material*		3.2	
Bones and offal	0.6	0.5	0.3
Total garbage	13.6	12.6	14.3
Rags	0.4	0.4	0.4
Metals	0.9	1.0	0.4
Glass	0.5	0.45	0.3
Bottles	1.0	1.0	3.0
Crockery	0 6	0.55	
Total rubbish	3.4	3.4	4.1
Total refuse	100.0	100.0	100.0

* In America paper and much of the fibrous material is more usually classified under rubbish.

TABLE 7.—Percentage of Water, Combustible Matter and Incombustible Matter in Mixed Refuse, excluding Street Sweepings.

	New York.			London.			Berlin.		
	Water.	Comb.	Incomb.	Water.	Comb.	Incomb.	Water.	Comb.	Incomb.
Ashes	...	20.3	60.7	...	23.9	58.1	....	1.6	51.6
Garbage	8.4	3.3	0.3	9.0	4.5	0.5	19.2	12.2	0.6
Rubbish	...	6.3	0.7	...	3.6	0.4	....	13.5	1.5
Total	8.4	29.9	61.7	9.0	32.0	59.0	19.2	27.3	53.5

TABLE 8.—Amount of Refuse in Four Large American Cities.

Cities.	Author.	Total refuse per annum, in tons.	Population served.	Refuse per 1 000 persons per annum, in tons.	Refuse per capita per annum, in pounds.
New York.....	Craven.....	1 699 000	2 049 000	825	1 670
Boston.....	Sullivan.....	391 000	530 000	740	1 480
Washington.....	Stutler.....	171 000	300 000	570	1 140
Baltimore.....	Wickes	380 000	509 000	750	1 500

A weighted average would be about 750 tons per annum per 1 000 persons, or the equivalent of 1 500 lb. per capita per annum.

Chapin* gives the average weight of garbage per cubic yard as being from 1 080 lb. in St. Louis and 1 100 lb. in Boston to 1 500 lb. in Washington, Lynn, Brockton and Pittsburg.

Table 9 gives perhaps the most useful figures. It will be observed that the quantity of refuse per 1 000 persons in New York is much the largest, being 835 tons per diem, while the corresponding figures for London are 400, and for Berlin, only 300 tons. Maxwell states that the amount of refuse in England varies from 250 to 500 lb. per capita per annum. From other evidence, although neither given in figures nor with authority, it appears that the figures for garbage may be too small for London and too large for Berlin, possibly due to different classification.

TABLE 9.—Approximate Average Amounts in Tons per Annum per 1 000 Population of Various Classes of Wastes in the Mixed Refuse of New York, London and Berlin.

Material.	New York. (Craven.)		London. (Codrington and others.)		Berlin. (Bohm and Grohn.)	
	Per cent.	Tons.	Per cent.	Tons.	Per cent.	Tons.
Ashes.....	66	550	48	192	31	93
Garbage	10	85	9	36	19	57
Street sweepings.....	18	150	40	160	41	123
Rubbish.....	6	50	3	12	9	27
Total.....	100	835	100	400	100	300

* "Municipal Sanitation in the United States," by C. V. Chapin, 1901.

The amounts per capita per annum in the United States may be roughly stated to range as follows:

Ashes	300	to 1 200	lb.
Garbage	100	to 180	"
Rubbish	50	to 100	"

Table 10, equally useful, was prepared from the foregoing data by utilizing the information given by the same authorities regarding the quantity of combustible and incombustible matter contained in the ashes, garbage and rubbish and the water contained in the garbage, leaving out the street sweepings.

From Table 10 it will be observed that the moisture is greatest in New York, being about twice as much as the average for London and Berlin. The combustible matter left in ashes is greatest in New York and almost nothing in Berlin. The combustible matter in garbage alone appears to be greatest in New York and twice as much as in London; in rubbish it is greatest in New York and least in London. In New York and London there is about 3½ times as much combustible matter as there is water, and in Berlin only 1½ times as much.

TABLE 10.—Approximate Average Amounts, in Tons per Annum per 1 000 Inhabitants, of Water, Combustible and Incombustible Matter in the Mixed Refuse of New York, London and Berlin, exclusive of Street Sweepings.

	New York.			London.			Berlin.		
	Water.	Comb.	Incomb.	Water.	Comb.	Incomb.	Water.	Comb.	Incomb.
Ashes	.....	138	412	.....	56	136	.....	3	90
Garbage	58	24	3	22	12	2	33	22	2
Rubbish	.....	44	6	.....	10	2	.....	24	3
Total	58	206	421	22	78	140	33	49	95
		(685 tons.)			(240 tons.)			(177 tons.)	

Mixed refuse, as compared with garbage alone, materially affects the moisture content of the latter. The fine ashes and dust draw

its water from it by capillarity and absorb and later evaporate the same.

From the calorific values, given under the separate materials, it is practicable to get an approximate value in each case of the burning qualities of mixed refuse.

Experience has demonstrated that whether or not steam is to be raised by the burning, it is generally economical to obtain as high a temperature for the combustion as possible.

The plenum system for draft introduced by Horsfall is especially fitted for producing high temperatures. An exhaust flue over the hottest fire is advantageous in burning all fumes given off by the refuse on the grate or hearth.

The advantage of raising steam from mixed garbage has been fairly well demonstrated in England and Hamburg. The European refuse as a rule evaporates its own weight of water at 212° fahr. From Table 11 it will be seen that from ½ lb. to 2 lb. of steam are produced from 1 lb. of refuse, depending on the material, a careful management, the season, and the amount of combustible matter in the refuse. Steam pressures obtained in England range from 100 to 200 lb. per sq. in.

TABLE 11.—Average Evaporative Power of Towns' Refuse Obtained in Practice. (Hutton.)

Description.	Weight of water in pounds, evaporated from and at 212° fahr. per pound of refuse fuel.
Screened ash pit refuse, the best	2.00
" " " averages	1.50
Unscreened ash-pit refuse, the best	1.25
" " " averages	1.00
" " " of inferior quality seldom exceeds	0.75
Unscreened ash-pit refuse (two parts) mixed with street sweepings (one part) by weight	0.75
Unscreened ash-pit refuse (two parts) mixed with street sludge (one part) by weight	0.50

Refuse described in Table 11 yields on the average from 25 to 35% of clinker and ash, and the greatest heat developed ranges from 1 500 to 2 000° fahr.

In Berlin, where the amount of unconsumed coal in the refuse, according to the experiments made by Bohm and Grohn, is very much less than in England or America, only about 0.33 lb. of water can be evaporated on the average per pound of refuse burned.

In American cities there seem to be no authentic records of cases where either garbage alone or mixed with ashes and rubbish have been utilized to produce steam. When burning garbage alone it has always been necessary to add coal. But even in this case there are few records available which show just how much coal was used to burn the garbage. At Trenton, N. J., coal, to the extent of 7% of the weight of the refuse was found necessary to burn a mixture of garbage and general rubbish, the garbage containing 80% of water.

The furnaces for the destruction of rubbish in Boston and New York have generated steam for mechanical purposes. In these two cities, respectively, $1\frac{1}{4}$ and $1\frac{3}{4}$ lb. of water were evaporated per pound of rubbish, which is about one-fifth to one-eighth of the evaporative value of ordinary coal.

Collection.

It will be evident that the method of collecting the materials just described also forms an important part of the work under discussion. Not only will the objectionable qualities of the refuse require special precautionary consideration and special methods of handling, but the element of cost of transporting alone sometimes becomes sufficiently important to decide the method of final disposal. Great distances for hauling may act against the economy of operating a single plant. Conversely, the method of disposal to be adopted sometimes controls the necessary manner of collection. For instance, feeding to swine or extraction of grease demand that garbage be collected separately from all other refuse.

If all or several parts of the refuse can be collected at the same time in the same vehicle, the apparatus, carts, etc., may differ from those which are required when but one part is collected separately.

It will be more convenient for the present purpose to consider separately the conditions pertaining to each of the four classes of refuse. If several classes are combined the necessary amendments to the systems of collection thus determined may be readily deduced from what will be said.

Ashes.

To avoid the chief objectionable feature in ash collection, namely that of dust, it is necessary to use covered receptacles, into which the material is placed at the house, and covered carts or wagons by which it is removed.

There are now in use here and there several patterns for receptacles and carts which have been proven satisfactory. The material of which they are made is preferably iron or steel. To avoid the nuisance of dust arising from the process of dumping, the carts should be emptied carefully, and in windy weather there should be a prior wetting. As there is no putrefaction, the time or frequency of collecting ashes is of no sanitary moment.

Garbage.

Owing to the rapid decomposition, to the concomitant offensiveness and high degree of moisture of this material, it is generally conceded that it should be placed in water-tight and covered receptacles, and transported in water-tight and covered carts or wagons. These are best made of metal, except in northern climates where winters are long and cold and where wood is generally preferable.

Where garbage is likely to freeze while awaiting transportation, a conically-shaped receptacle is the proper form. Carts or wagons should have a shape which allows of easy and complete dumping and avoids any after shoveling. Sometimes it is desirable to have the body of the wagon so arranged that it can be lifted from the trucks at the works for separate conveyance to the point of dumping into tanks or furnaces.

Occasionally, it is necessary to have water transportation to the place of disposal, and for this purpose either flat-topped scows are used, from which the garbage must be shoveled, or self-dumping scows, from which it can be dumped at sea.

It is conceded that the collection of garbage must be quite frequent, varying with the season and manner of disposal. It should, in all cases, be made before putrefaction begins, and, when the garbage is not mixed with other refuse, the time of collection varies from daily for summer months in southern countries, to weekly for winter months in northern countries. If garbage is to be utilized for food in piggeries, then, a daily collection should be peremptory,

excepting only in freezing weather. If it is mixed with ashes a daily collection is not necessary.

Street Sweepings.

Street sweepings, on account of the occasional dust nuisance, should also be removed in covered carts or wagons, even if the streets are sprinkled just before sweeping. The collection should be made as soon as practicable after the dirt has been swept into small piles, so as to prevent both subsequent drying and re-dispersing by wind or travel.

The frequency of street sweeping is a question which has been determined in the United States more from financial considerations than from those of comfort or health. Each city has decided this question as it thought most convenient for local conditions.

In some large cities of the United States the busiest streets, and particularly those with asphalt pavements, are swept daily when practicable; in others, as in residential districts, once or twice a week, and still others less often. In some cities there is no sweeping at all in winter. Streets which are not much used are often cleaned but once a year. Macadamized streets and others that are not paved are rarely swept; they are usually repaired and leveled once a year and after heavy rainstorms.

In Europe the streets are cleaned, as a rule, not only more frequently but more thoroughly than in America.

It should be added that the appearance of the streets and effectiveness of cleaning depends practically more upon the kind and condition of pavements than on any other one item. A smooth and hard pavement, such as asphalt, can be more thoroughly cleaned than any other. In Europe a thorough washing and use of the squeegee is quite common and keeps such pavements in an excellent condition. To maintain a clean block pavement economically, the blocks should not only be of hard and tough material set on a concrete foundation, but dressed with smooth tops and joints only about $\frac{1}{4}$ in. wide. The celebrated Liverpool granite pavements of the last century owed their excellence to the fulfilment of these conditions, and many other European cities followed the example.

Street sweeping is still mostly done by hand. Machines, however, are rapidly being introduced for this purpose in the large cities.

Rubbish.

The removal of general rubbish should be made in covered vehicles to prevent odors, dust and other nuisances. Due to the dry condition of this material and to the fact that it does not readily decompose, the frequency of collection is not an important matter.

Combined Refuse.

The collection and removal of combined refuse should be made in covered wagons, because every one of its parts requires this precaution.

The frequency of collection depends on the character of the combination. The garbage ingredient, because of its ready decomposition, determines the period, which is governed by the liability of creating a nuisance. If garbage and ashes are mixed, the speed of decomposition is reduced, and the more ashes are added the longer can be the period between removals. Its proper length will be indicated, therefore, by the facts and experiences in each particular case.

The receptacles and wagons for combined refuse will necessarily be of the size, shape and material to meet local conditions and the requirements of each part of the refuse, in the light of what has already been said. Fulfilling the requirements both for ashes and garbage will generally fulfill them also for the other parts of the refuse.

Disposal.

After discussing the character of the refuse materials and their collection and transportation to the place of dumping, the important question of final disposal may now be considered.

To be satisfactory, the disposal must answer two requirements; it must be sanitary, *i. e.*, without nuisance or danger to health; and it must be economical, *i. e.*, the expense must be the least that will effect a sanitary final disposition of all the materials. Under the present heading will be considered only the first requirement, leaving the question of cost to be considered later.

It will be found best to take up separately, as before, each one of the four classes of refuse, for examination with reference to preserving satisfactory sanitary conditions. In doing so, account will

be taken of the facts and conclusions that were stated while discussing the materials themselves.

Ashes.

When they contain unburnt coal, ashes are valuable as a fuel to the extent of the units of heat which can be developed. They have, therefore, been utilized to burn the objectionable refuse so far as practicable.

With or without this coal, ashes can be satisfactorily used also for filling in low lands, which in the United States is, in fact, their usual disposition.

When containing very little coal, ashes have been and can be utilized for road making and also as a substitute for sand when making mortar.

Garbage.

Garbage, due to its composition, can be utilized and disposed of in a number of ways. The objectionable qualities have been stated as being rapid putrefaction, offensiveness and potency to serve as a carrier for disease. The valuable qualities are its uses in part as food, manure, grease and combustible matter. As these qualities give to this material a greater value than any of the other parts of the refuse possess, it becomes the most important part thereof.

The final disposition of this material is now being effected in the following ways:

1.—Feeding to swine;

2.—Dumping as filling;

3.—Digging into soil or burying;

4.—Dumping into large volumes of water;

5.—Extracting the grease;

6.—Cremating the organic matter.

Feeding to Swine.—The food value of fresh garbage is sufficiently great to have made feeding to animals, and particularly to swine, an old and still a very common method of final disposition. In the small and medium-sized cities of New England this method prevails to-day. In fact, probably every city disposes of some of its garbage in that way. Hotels and eating houses quite generally have private collections for this purpose, because of the profit from such sales, even where the municipality has a public disposal system.

In order to preserve a value for feeding purposes, the garbage must be kept free from other refuse and whatever would injure its food quality. It must be collected promptly and delivered daily, so as to prevent its prior putrefaction. With care in this respect, there can be no objection from a sanitary standpoint to this method of disposal. Such food will neither injure the swine nor will the material have offensive odors.

In the 160 cities of the United States having over 25 000 inhabitants, 35 dispose of most of their garbage by feeding it to swine. In the smaller cities this disposal is even more frequent.

Dumping as Filling.—Where feeding is objectionable, and the garbage is mixed with other refuse, dumping on waste land is often practised. Among the 160 large cities of this country about 40 make this disposition of it. The method is objectionable in some cases, in others not, depending on the character of the locality of the dumping ground, and on the proportions of the mixture. It should of course not be practised where there can be an offense from subsequent putrefaction.

In dry climates there is a gradual dessication of the garbage thus deposited. In moist climates putrefaction will hasten the complete decomposition, and unless the garbage is covered with soil offensive conditions will arise.

Digging into Soil, or Burying.—A better method than the foregoing, although a more expensive one, is practically a shallow burial of the garbage. This method is practised in about 15 of our largest cities. A few years ago it was seriously considered for adoption in Berlin, Germany.

The advantage of shallow burial lies in the conversion of the organic matter by nitrification into a fertilizer which in sterile soil can increase its productivity and thereby may raise the value of the land. The method is practised either by digging or plowing trenches into which the garbage is placed, or by spreading it over the ground and lightly covering it with soil. If suitable land is available for this purpose, if freed from metals and large entangling objects, and if the soil is barren or acid, garbage being somewhat alkaline, and if the expense is reasonable, there are no valid objections to this method. It disposes of any possible disease germs and odors.

Dumping into Large Volumes of Water.—Like the disposal of sewage by dilution so can garbage be dumped under proper precautions into the water of large rivers or into the ocean, without offense. To prevent the floating matter from returning to the shores of Long Island and New Jersey, the New York garbage had to be towed about 20 miles out to sea. In a large river, such as the Mississippi at New Orleans, where garbage can be dumped into the central current and neither drifts ashore nor can obstruct the navigable channel by deposition, this method can be practised with impunity. There will be few instances, however, where this would be the case.

Extracting the Grease.—The extraction of grease from garbage is an American industry which has been promoted during the last 20 years in a number of cities.

The process consists, briefly, in causing the garbage to be separated into three parts: Water, grease, and a dry material, somewhat stable, mostly fibrous and of vegetal and animal origin, called tankage. The grease is oil or fat which has a selling value of from two to four cents a pound, and is utilized for a number of purposes. The tankage is used as a filler or diluter for certain fertilizers, and in some cases it is used as fuel or dumped on land.

The separation is brought about by one of several processes: the Merz, Simonin and Arnold systems, and others of less importance.

The Merz process was the first in successful use and is still used in St. Louis. It is briefly described as follows: The garbage is dumped into a hopper from which the superfluous water drains off. It is then spread out and as much foreign matter as possible, such as cans, bottles, rags, metal and bones, is picked out and sold. Then it is dumped into hot-air driers and stirred with mechanical mixers for about six hours, when it has become comminuted and is dark brown and greasy. In this condition it is put into extractors or closed tanks into which naphtha is made to percolate for the purpose of dissolving and thereby extracting the grease. The grease solution is drawn off, separated from the naphtha, barreled and sold. The naphtha is vaporized, then condensed and used again. The tankage is ground, sifted and sold for fertilizing purposes, or has been used in its natural state for fuel.

The Simonin process is quite similar. While naphtha is used for the grease extraction, it is applied directly and obviates the necessity of a prior drying. The garbage is dumped into pans on cars which are then run into the extractors. These are subsequently closed tightly and naphtha is allowed to fill them. The garbage and naphtha are then heated by steam coils placed in the bottom. The grease is dissolved by a portion of the naphtha, and the heat evaporates the remaining naphtha and water. The latter pass off as vapor into a condenser to be liquefied and then flow into a separator, from which the water flows into a sewer and the naphtha into a tank from which it is drawn for repeated use. This evaporation is continued until nearly all the free naphtha is driven off, and a solution of grease remains at the bottom of the extractor, from which it is drawn off and forced into a settling tank; then it flows to a still where the naphtha is removed by steam heat and finally is drawn off into a tank from which the grease is barreled for shipment. The garbage held in the extractor is heated several times until all water is removed. The naphtha, remaining after the grease solution is drawn off, is driven off by live steam, after which the dry tankage is taken out and disposed of. This process takes about 48 hours.

The Arnold process is used chiefly in New York, Philadelphia and Boston. It is the simplest and apparently the most successful and least costly. The garbage, after picking out metals, glass and other undesirable stuff, is dumped into digestors, holding each about eight tons. In them the garbage is cooked several hours under pressure with live steam. It is then allowed to fall through a valve at the bottom into a continuously rolling press which separates the fluid from the tankage. The fluid consists of grease and water which are subsequently separated by gravity, the water flowing off into a sewer and the grease into tanks to be barreled and sold. The remaining solid matter or tankage is dried and then either ground and sold as a filler for fertilizers, burned or wasted.

All reduction works are naturally more or less offensive, and great care is required to prevent a nuisance. As they are all operated by private concerns for profit, it is necessary for the public to enforce such care, and the consequent restrictions add to the cost.

It must be realized that from 5 to 10% of the garbage, consisting of cans, bottles, metal and other refuse which is neither productive

of grease nor of desirable tankage, should be separated by picking prior to treating. This picked-out residue of course requires a separate disposal.

The reduction process is confined to and is in successful operation in some 20 of our largest cities, due to the fact that through our wastefulness garbage in America contains a larger quantity of grease than in Europe, and to the fact that the necessarily large investment for the plant is profitable only when a large quantity of garbage can be treated. On the other hand, in its earlier development, it has been abandoned in a number of cities generally because the works were not found profitable.

Cremating the Organic Matter.—To burn up all the decomposable matter contained in the garbage, and thus to destroy all germs of disease and the causes of offensive odors, has been the favorite method of the medical profession, and is the favorite and exclusive one so far adopted in Europe. Although theoretically an ideal process, practically it has often fallen short of expectations, particularly in America, where such works have often been complained of as nuisances, and have subsequently been abandoned for other methods.

About 35 cities out of 160 in the United States of over 25 000 inhabitants dispose of garbage by cremation.

In Europe cremation has been a success. New works are erected every year and complaints are rare. The reasons why results have differed in Europe and America, and why the elements making up the problem are not exactly the same, have been stated on another occasion substantially as follows:*

"The material as it is burned in Europe has not the same composition as that which here has failed to burn properly. European success was achieved with refuse generally consisting of a mixture of garbage with ashes and dry combustible rubbish. The chief failures in America are recorded where garbage alone was cremated, without the admixture of other combustible dry refuse, and even after the addition of furnace coal.

"The essentials in the construction of the successful English furnaces differ from those of the furnaces peculiar to our country, where they have not been satisfactory. The English furnaces are built with sloping grates of small area, while the American furnaces generally have horizontal grates of large area. A sloping grate

* *Transactions*, Am. Soc. C. E., Vol. L, p. 100.

admits of an almost automatic, continuous process of gradual drying, then heating, and finally burning; the fresh material being added at the upper end and the hottest fire being near the lower end. A horizontal grate, on the other hand, to secure proper combustion, depends almost wholly upon stoking. It causes the burning to be irregular, due to the sudden dropping of cold and perhaps wet material upon that which is already almost completely burned. In Europe we find also an extensive use of large dust chambers to prevent the escape of this fine material, of which we so often hear complaint. We find also a more frequent and effective placing of dampers to control the draughts, and thus prevent the escape of unburned, and therefore odorous, solid particles and gases. Finally, more attention is directed there than here to the evolution of the greatest possible heat for the incidental production of steam.

"The expert garbage fireman, who is considered essential to success in England, is generally supplanted here by a man whose only qualification for the position may be that he can shovel coal or pull out clinkers, but generally has not the remotest knowledge or even conception of the difficulties in burning, on a large scale, both continuously and completely, the most heterogeneous mixture of all forms of solid matter to be gathered from a modern community. The advantage of a trained expert in firing city refuse was well shown by the fact that until Hamburg imported English firemen to train the German firemen in the mere operation of their own plant, satisfactory results could not be obtained.

"In Europe, the municipalities, under the guidance of experienced engineer officers, generally undertake the cremation by their own long-trained employees, while here, usually, either the health boards or council committees select not only the design, but indicate the method of operation, appoint inexperienced employees, or enter into a contract for immediate profit rather than for permanent efficiency. The difficulties underlying the problem of city refuse disposal, which is almost wholly one of engineering, have been solved satisfactorily where competent engineers have been employed for the purpose. It is hardly to be expected that, without professional skill and training, desirable results can be reached in this, any more than in any other, branch of engineering."

The modern system of municipal refuse burning had its origin in 1876 in England through the erection of a group of furnaces by Mr. Alfred Fryer at Manchester.

The unit furnace of the Fryer type consists of a pair of cells usually placed back to back, each having from 25 to 30 sq. ft. of grate surface. Back of the grate is a drying hearth on which the refuse is dumped, a single feed-hole or hopper serving both cells.

Both grate and hearth have a forward slope at the rate of about 1 in 3 and a width of about 5 ft. For the escape of the fumes a flue connects above either the grate or the hearth with the main flue situated between the cells.

The refuse is moved forward to the fire-bars by raking from below through the fire-door and by pushing from above. The clinkering is done when the material is thoroughly burned, at intervals of several hours or oftener. The clinkers accumulate in front and are then raked out of the furnace.

The draft is natural, the air entering below the fire and generally passing over the drying refuse into the flue. In the early days the draft was controlled entirely by the chimney and its dampers.

By cooling when passing over the drying hearth, the gases often remained imperfectly burned. High chimneys with high velocities permitted the occasional escape of dust and unburned particles. To avoid these defects the fumes were sometimes passed over a second fire or fume cremator, but with very moderate success.

Then came an important improvement in the introduction of forced draft to produce a high temperature. Air was forced into the ash-pit and was taken out over the part of the grate where the fire was hottest. To improve combustion still further, Horsfall modified the former designs by introducing a steam-jet into the closed ash-pit in all cases where great heat could be produced. The steam when passing through the glowing cinders is decomposed and produces a "water-gas" effect. A steam-jet or forced draft as against natural draft requires a smaller chimney.

The drying of refuse on the hearth was improved by passing the hot fumes around it on their way to the flue. There were also improvements in dampers and dust catchers.

Automatic arrangements were introduced for saving labor in various ways, but no important improvements in this direction have survived, for the evident reason that the refuse varies so much in quality that in most of the operations nothing less than constant watchfulness and intelligent adjustment will secure satisfactory results.

The Warner furnace is similar to Fryer's and has also been very successful. It has an improved charging arrangement, consisting of a hopper with a movable bottom which allows the dumping to be arranged at will.

The Meldrum furnace is another variation, and departs materially from the Fryer principles. Instead of a hopper with automatic feeding, this furnace is generally fed by hand, and instead of the cells being entirely separate, a number of them are united and placed side by side. Yet the ash-pits are still separated, each being supplied by forced draft of air or steam. The grate-bars are horizontal. The advantage of thus uniting the fire space of the cells is the attainment of an approximately constant temperature which is desirable for steam raising.

The feeding is done from the top, as in the furnaces previously mentioned; or, it is fed either from the back, the hearth and grate sloping to the front, or through hoppers directly over the grate in the front part of the cell.

After leaving the fires the fumes pass around several rows of baffle pillars to equalize velocities and heat, and being at white heat, they also act as a fume cremator. The fumes are then carried either directly up the chimney or to a set of boilers.

A still more recent variation of furnace is the Beaman and Deas destructor. It retains the self-feeding open hopper and also the hearth, but this has an inclination of 50°, and on its bottom slope a screen allowing dust and fine material to drop into a pit and not reach the fire. The grate surface is about 5 ft. square and level, and there is forced draft. The grate-bars are stationary and set quite closely. Beyond the grate is the fire-bridge, and beyond this a combustion chamber. The air-blast pipes enter the air-tight ash-pit under the bridge. The air itself is supplied by fans and its circulation controlled by valves, as in other furnaces.

The fumes from the refuse drying on the hearth pass over the fire and are thoroughly burned. The bridge contains air passages leading from the outside of the furnace to the combustion chamber and supplying fresh air at a high temperature. The combustion chamber is provided with special doors for the admission of infected or other dangerous articles.

An excellent, and perhaps the largest and best, refuse destructor plant is at Hamburg, Germany, and was designed by Mr. J. Andreas Meyer, City Engineer. It was built about six years ago, and was based chiefly on the Horsfall improvements, although forced air was preferred to the steam-jet.

Returning to America, a few of the more common furnaces for burning garbage will be described.

The following descriptions should be prefaced, however, by the statement that a few Southern cities burn a mixture of their garbage and rubbish in the open air, claiming it to be satisfactory, but admitting that odors arise from the process. It is clear that such a system, while it may cost less money, cannot be acceptable to most cities.

The Engle furnace was the earliest built in this country for public purposes. It is typical of the present American type of furnace, and has been used extensively. A rectangular fire-chamber, about 40 by 10 ft. with horizontal grate surface, receives the garbage, which is dumped into it through feed-holes from above. Little attention is paid usually to the condition of the garbage as to moisture, fineness of material or amount of combustible matter. Coal is used for firing, sometimes in fairly large quantities, and is burned upon special grates at both ends of the furnace. The flames from the coal fires pass over the garbage from the front fire to the rear, where the smoke and gases are supposed to be consumed. From the latter fire the fumes are brought back underneath the grates, heating the garbage from below. Unless the garbage upon the grates is carefully packed, the air is drawn through on a short cut and misses the second fire. Many of the Engle furnaces have been abandoned on account of either inefficiency or cost. This furnace was used for destroying refuse at the World's Fair in Chicago. The fuel was natural gas and was plentifully used. The result was efficiency, but at high cost.

The Dixon furnace has also been used extensively. The early designs resembled the Engle furnace in its chief features, namely, the large horizontal grate, the dumping from above, the separate coal fires, flues, dampers, etc.

In a later design, intended to be used for small cities generally, not producing more than 15 tons daily, the garbage is subjected to a preliminary drying in a separate compartment directly above the combustion chamber, and into which it is dumped through suitable openings. It has but a single coal fire, the secondary fire being omitted. The stenches are expected to be removed thoroughly by letting the fumes pass through a checker-work of what the inventor terms "stench tile."

The latest design is at present installed on the World's Fair grounds in St. Louis. It consists of the following parts:

a.—A charging platform extending over the furnace with feed-holes or charging hoppers through which the garbage is dumped upon the grate.

b.—The main combustion or destroying chamber, 34 ft. long, 6 ft. wide and about 5 ft. high. It has curved grate-bars, which are highest in the center and upon which the garbage is dumped from above.

c.—An ash-pit or evaporation chamber below the grate, of about the same length and width as the destroying chamber and about 2 ft. in height.

d.—A coal grate at the front end of the destroying chamber, about $2\frac{1}{2}$ by 4 ft., where a fire can be maintained, the fumes and heat from which pass over the garbage to a fire-bridge at the other end. 34 ft. distant, over which it descends and passes into a firebox under a third grate to be mentioned later.

e.—A second coal grate of equal size, and situated just below the one last mentioned is to have a fire maintained for the purpose of having the heated air pass through the ash-pit, to assist the combustion of the garbage resting above it, and to evaporate the moisture and water which has dropped into the ash-pit.

f.—A third coal grate, $2\frac{1}{2}$ by 5 ft., is located in a separate compartment at the end of the chambers nearest the stack. The fumes enter this compartment above the grate both from the destroying and evaporating chambers. The fire on this third grate is maintained for the purpose of destroying finally and completely all stenches arising from the fumes. To make this destruction more effective, the fumes or gases pass through a checker-work of so-called "stench tile." These tile rods, of which there are about 40, are placed horizontally several feet above the grate and are heated to white heat by the fire kept burning upon it and thus thoroughly burn the fumes.

g.—A screen chamber adjoins this compartment into which the gases leaving the stench tile are led. This chamber, about 4 ft. 3 in. by 5 ft. in section, has the double purpose of providing means for heavy dust to settle at the bottom and to prevent large suspended matter from rising into the stack by the interposition of a wire screen of 1-in. mesh.

h.—A breeching flue with damper, and a stack which is 100 ft. high.

Another typical furnace is the Smith crematory. It consists of several furnaces grouped in pairs around an apparatus for the generation of gas which is to be used as fuel. Each furnace is an upright iron tank lined with fire-brick, and is connected with its twin by flues, on one side by a flue leading from the gas generator to the chimney, and on the other by a short direct flue. After leaving the furnace the flues on their way to the chimney first lead to chambers in which is a checker-work of fire-brick, resembling the so-called "stench tile" of the Dixon furnace. The garbage is dumped from above into a receiver without a grate, and burns only on the top. These receivers are charged and operated alternately. The gas passes directly from the generator to the charged receiver through a flue, where it is mixed with air. The flame attacks the garbage and passes to the other or empty receiver and thence to the flue. The checker-work of fire-brick is expected to be so intensely heated that the fumes are freed of objectionable odors by their complete destruction.

Still another type of the American furnace is the Davis crematory. It consists of:

a.—An arched drying chamber about 8 ft. square, into which the garbage is dumped through a feed-hole. At the bottom is a horizontal grate, chiefly for drainage purposes. At intervals the garbage is raked down into the combustion chamber.

b.—An arched combustion chamber about 4 by 6 ft., placed in front of and at about the same level as the drying chamber. It has a horizontal grate upon which coal is thrown to assist the combustion.

c.—A main flue with regulating dampers and screens to intercept larger particles escaping from the fires.

d.—A secondary grate, 2 by 4 ft., and a flue for auxiliary fires to eliminate odorous fumes on their way to the stack.

e.—An evaporating pan under the grate in the drying chamber.

f.—Grate-bars, 4 ft. long and 4 in. wide, with ½-in. openings for fire grates and ¼-in. openings for drying grates.

g.—Feed-hole, ash-pits, firing and observation gates.

h.—High chimney.

Other furnaces have been built and are in use, resembling more

or less the above-mentioned types, and called the McKay, Brown, Brownlee, etc., furnaces. Of the cities which have recently reported on the disposal of garbage by cremation, it was found that the Engle furnace was used in seven, the Dixon in eight, the Smith in three and the Davis in two.

Furnaces of the English or Fryer type have been built and operated in Montreal with fair success,* and also in San Francisco.

Speaking generally regarding the design and operation of furnaces for the cremation of garbage, it must be repeated that there is a material difference as to whether garbage is burned alone or mixed with other refuse. If burned alone, it is readily seen from the available analyses that a very large quantity of moisture must be evaporated before combustion can take place. Account must be taken of this fact. In the United States, where this practise of burning garbage alone has been introduced in a number of cities, it is generally drained and sometimes also dried, before it is subjected to great heat for combustion, and then the assistance of coal fires is still necessary.

When dry rubbish is mixed with the garbage, a great deal of the moisture is absorbed and then slowly evaporated. Garbage combustion, therefore, requires less coal to be added, the rubbish itself containing much more combustible matter than is necessary for self-burning. When domestic ashes also are added, with the usual large percentage of unburned coal, then, unless there is present an excess of fine dust, the entire refuse is capable of burning itself practically without the addition of any fuel, as in England, Hamburg, Montreal and San Francisco.

Ashes mixed with garbage act as an excellent deodorizer, as well as an absorbent of moisture, which greatly alleviates the dust nuisance.

To improve the combustion it is economical in most, if not all, cases to screen out the fine dust before the material is put into the furnace. This screening may be done either when ashes are mixed with rubbish or when separately collected. If ashes are mixed with garbage, the screening probably would be done at the furnace. This dust, obtained by screening mixed refuse, rarely contains more than 10 to 15% of organic matter, and can, therefore, be disposed of

* "Refuse Disposal in Montreal," by Dr. Elzear Pelletier. *Papers and Reports*, American Public Health Association, 1902.

by dumping without causing any nuisance. This small amount of organic matter is at once disinfected and soon oxidized.

Much of the success of garbage cremation naturally depends upon the design of the furnace, which must be capable of generating enough heat to burn the organic matter and offensive gases completely.

There are furnaces with natural draft, with forced draft and with steam-jets. Natural draft, commonly used in the United States, requires high chimneys. On account of the resulting high velocities of the escaping gases, there is also a tendency to expel unburned particles. The air drawn naturally through the fires is not always sufficient in quantity to create rapid combustion and generate great heat. In Europe, therefore, forced draft is much preferred. Steam is forced under the grate in the Horsfall furnace, and air in most of the other English furnaces and in Germany. Forced draft allows lower chimneys to be built. It produces much higher temperatures and can be operated with smaller chimney velocities. A blast of air or steam prevents clinkers from adhering to bars.

Of much importance is the preliminary drying of garbage when unmixed with other matter, because its water content often reaches 80 or 90 per cent. Some of this water will naturally drain off by gravity. It has been suggested to press it out, if economical means for this purpose are at hand, or to use rotary dryers which are now in the market for other purposes. A careful inquiry into the economy of such special apparatus in each case will determine its value.

The usual method of drying is by the final heat of the burning refuse. The gases of combustion are allowed to pass over, under, around and, sometimes by means of special pipes, through the garbage. By contact or radiation the material is thus dried and prepared for reception upon the grates.

Every furnace should be arranged to prevent accidental escape of dust. This escape can be prevented by reducing the velocity of the fumes on their way to the stack to between 1 and 1½ ft. per sec., which is effected by passing them through a greatly enlarged space or dust chamber, in which the dust will settle, or by contrivances such as centrifugal expulsion (Horsfall dust catcher). The

escape of large floating particles, such as burnt paper and the like, is prevented by screening the fumes. Douglas Fox found in 1 cu. ft. of air in the combustion chamber 0.18 g. of fine dust. The specific gravity of the latter is only 1.989 (Stevenson Macadam), while the specific gravity of road dust is 2.34.

To control the working of a furnace properly it is desirable to have instruments which record temperatures, draft and steam pressures. It is also desirable to have a periodical testing or analysis of the gases, and particularly of the characteristic mixtures, as they vary by hour, day and season.

The differences between horizontal and sloping grates have an important bearing upon the results. In America, horizontal grates are chiefly used, and the material is dumped from the top. On the horizontal grates the practise of top dumping cannot be so effective as when the material is thrown upon the grates by hand, as is done in the Meldrum furnace. This is due to the possibility, in the latter case, of sorting the material required at each moment for the most effective combustion. Top dumping through a single feed-hole is not as well adapted to horizontal as to sloping grates, such as are used in the furnaces of the Fryer pattern, where the loads of material, as they are delivered at the crematory, can be selected, at least roughly, when dumping into the hopper, after which they are fed automatically to the grates.

It is much better to let the fumes, when leaving the furnace, enter the flue over the hottest fire than where the combustion is less complete.

With properly designed furnaces success will still depend very largely upon the management of the works, namely, upon a judicious selection of the material and intelligent operation.

The loads as they are delivered may not arrive in the order in which they can best be dumped upon the fires, or even into the drying chamber from which they are drawn or slide to the grate. Therefore certain loads should be dumped on the platform near the feed-hole to await the proper time for insertion by hand labor.

Care should be taken when raking the refuse to spread only thin layers of unburned matter upon that which is burning, so as to prevent the blackening or deadening of the fires. The burning matter should be about 9 in. thick upon the grate to secure a clear

fire and yet allow sufficient cover to prevent forced air from blowing holes through the mass.

Care must also be given to the operation of the dampers, particularly when opening the feed-holes for charging, or the front doors for stoking or clinkering, so that large quantities of cold air do not flow upon the fire. It is of the utmost importance to control the velocity of the gases at all times to prevent dust, unburned gases and floating matter from escaping through the chimney.

It is, therefore, evident that more than ordinary intelligence is required for such work, even a special training and experience in this particular class of firing, if success is to be expected. Therefore large works are apt to be more satisfactory than smaller ones, because it becomes practicable to pay the wages of an experienced foreman, or chief stoker, to instruct and guide the men under him.

The ill-success of many of our furnaces is no doubt chiefly due to the ignoring of one or more of these considerations. This ignorance results either from inattention to the difficulties surrounding the work, or from underrating the importance of obtaining the most suitable designs and the most intelligent management. Both these essential requirements seem strangely lacking of full appreciation. Especially is there undervaluation of the necessity of having operators with a good practical knowledge of how to obtain a complete combustion of such a complex material as garbage and rubbish, of the effects and interaction of drafts from furnaces operated separately but leading into the same flue, of preventing unburned matter from being blown out, and of the means for settling the dust. As soon as these and other essentials for garbage operation are more fully appreciated, proper solutions on the part of the engineering profession will follow.

It might be added that in England much is said and written in favor of the production of power by the disposal of refuse by cremation. There is also the valuable example of Hamburg in thus utilizing the combustibility of its refuse. Just how valuable an asset this power production will be in the United States after all credits and debits will have been finally compared, remains to be seen. It is already clear, however, that the first requisite will always be a sanitary destruction of the objectionable parts of the refuse. If the cost of doing this can be reduced by the development of power,

it will be well to do it. But the production of power must ever remain secondary in importance, and it must be supplemented in all important works by another source of power, should the sanitary destruction of the refuse require a temporary employment practically of all the available heat obtained from refuse destruction for this purpose alone.

Street Sweepings.

When street sweepings contain a sufficient amount of fertilizing ingredients to warrant their separate removal to fields, their final disposal in this manner is proper and entirely acceptable.

It has also occurred that the content of organic matter was sufficient to burn this material with the other refuse. To this disposal also there is no objection if the expense is warranted, from the fact that the calorific value is not high. Often, however, this material contains much fine earthy matter, which is detrimental to the process of cremation, unless, as in the case of ashes, it is screened and freed from all dust. Such screening is, however, not generally to be recommended, because the fine dust of street sweepings may contain disease germs, which should be destroyed or made harmless.

Besides utilization as fertilizer, street sweepings can be properly disposed of as filling for low ground. When dumped, the upper surface of the material remains exposed to the wind, but only temporarily, until vegetation protects it.

Replies from 130 cities of over 25 000 inhabitants revealed that 32 disposed of their sweepings by cremation, 8 as fertilizer and 22 dumped them on land or at sea.

Rubbish.

The miscellaneous rubbish collected in a city consists of 80 to 95% of combustible matter. After the valuable parts have been picked out for sale, there are but two ways available for properly disposing of this material. One is by cremation and the other by dumping. Of these two methods the latter, although much used, is often objectionable. It is an old practise, and where suitable land is available, where such material will not cause future trouble and where it cannot be burned, dumping is sometimes

advisable for economical reasons. Cremating the rubbish is decidedly the best method of disposing of it, and should be used wherever possible, both for sanitary and often also for economical reasons.

In 127 cities of the United States with over 25 000 inhabitants, the rubbish is disposed of in 80 by dumping or filling on low land, in 24 by open burning on dump, and in 23 by crematories.

New York and Boston burn much of their rubbish in furnaces constructed solely for this purpose.

When mixed with garbage, destruction by fire is also the most desirable disposal. Rubbish contains sufficient combustible matter to burn not only itself, but, in America, where, as a rule, such matter is more abundant than in Europe, it can generally burn also moderately well-dried garbage.

Combined Refuse.

The proper disposal of combined refuse with or without street sweepings is practically limited to cremation. As already stated, this has been demonstrated satisfactorily in Europe. It is not practicable to utilize the combined refuse by any of the other methods previously discussed for the disposal of the separated refuse, and yet secure both a sanitary and economical result.

In American garbage the greater amount of moisture is probably fully offset by the greater amount of combustible rubbish and unburned coal, as before indicated.

From the general evidence at hand, it may be concluded with reasonable certainty, allowing for the fact that the figures are but roughly approximate, that combined city refuse in America could be disposed of generally by cremation as it is in Europe, without the addition of coal.

In 145 cities of the United States of over 25 000 inhabitants, about 20% combine their garbage with ashes and rubbish. Among cities of smaller size the proportion is probably greater.

Cost.

To estimate the cost of disposing of municipal waste, the assumption is necessary that, as in other engineering problems, the process is developed to a point of satisfactory efficiency. It is not proper,

therefore, to be guided by the cost of the operation of plants which have failed, or which have been considered undesirable. The available data to fulfill this requirement are scarce, and among them some are misleading, owing to special local conditions and practises.

In order to obtain reliable guidance in estimating the true cost of any proposed method of disposal, it is necessary to consider all expenses, beginning at the point of origin and ending at the point of final disposition. In other words, it must comprise the cost of both collection and disposal. One process may require a much longer haul than another. Then, to be economical, the disposal with a long haul must proportionately cost less than the disposal with a short haul. It is also possible that parts of the refuse, such as ashes, may be utilized quite near their origin, and that other parts, such as fresh garbage, may be best utilized by feeding to swine at quite a distance from the origin.

It would, therefore, be proper, strictly speaking, first to ascertain the cost of collecting and disposing separately of each class of refuse, in accordance with the several practicable ways indicated. Then, it might appear that perhaps some two or three, or all four, classes of refuse could be treated most economically by the same process. A second, or perhaps a third, estimate of cost for the best combinations would determine the most economical method or methods. It would then also appear whether or not a system of completely combined refuse removal, or a separation, was the better method, and in the latter case, whether or not any two or three parts could be collected and disposed of together.

In making such estimates of cost, account should be taken of both debit and credit sides of each part of the work.

The cost of collection is a debit in every case, comprising chiefly the expense of hauling, the amount depending largely on the distance to be hauled. It depends also upon the necessary frequency of collection, whether this must be a daily or may be a weekly one.

The cost of final disposition may result in a debit or credit, depending upon whether or not there is a net return from such disposition. In most cases there will be attached to it both an expense and a return from the sale of some parts or products. For the several classes of refuse the debits and credits might be as follows:

Ashes.—If wasted on a tract of land this land might have to be purchased. Returns would be secured from the benefits of filling or of utilizing the ashes for road making or mortar.

Garbage.—According to the method of disposal selected, expense will be attached to any preventive or precautionary measure against a nuisance or to the processes of digging it into soil, of extracting the grease or of cremating the organic matter. Incomes may result from its value as food, for making land and fertile soil, or producing grease, tankage, heat and power.

Street Sweepings.—The expense connected with the final disposal of street sweepings may relate only to the purchase of land for filling. A return may result from a value as fertilizer, fuel or filling.

Rubbish.—An expense may attach to the purchase of land for filling, or for the process of cremation. A return is yielded from the sale of the pickings, heat and power, and from the increased value of the filled-in land and fertilized soil.

An allowance should be made in the cost estimate also for the interest on investments, depreciation of the plant, and for whatever fixed charges there may be on the money invested in all branches of the work.

It appears to the writer that if the debits and credits are thus carefully ascertained, and cash values are given for all the available methods of collection and disposal, in each case it becomes practicable to ascertain which, among the best available methods, is the cheapest for any special case.

To get valuable evidence for comparison of the cost of collecting and disposing of refuse in American cities is quite difficult. The published cost generally includes collection. In most cases no measurements are made of the tonnage, and in many no account is kept even of the number of loads. Without knowing the quantities of the component parts, a useful comparison between different processes cannot be made.

The cost of collection is of little interest for the present purpose, as it depends wholly on local conditions, distances, grades and regulations for handling the different parts of the refuse, and can be readily ascertained for each case. It is generally between 50 and 75 cents per ton mile.

The cost of disposal is of more interest, and a few data regarding the same will be appended.

Goodrich* gives a carefully compiled table of the labor cost of English refuse destruction, indicating that it varies from 13½ to 68 cents per ton. A close examination, however, shows that for ordinary average conditions the cost of all labor including supervision ranges from 24 to 36 cents per ton. Stokers are paid from 12 to 15 cents per hour, and chargers from 10 to 12 cents per hour.

The amounts which should be added for the usual fixed charges of interest, etc., and depreciation, range from 10 to 15 cents per ton. It can, therefore, be said that the total expense for refuse cremation in England ranges from about 34 to 51 cents per ton. From this amount a credit should be deducted for the revenues resulting from the sale of material or production of utilized power.

In Hamburg the total cost ranges from about 40 to 50 cents per ton, and the revenues from 10 to 20 cents.

For the disposal of ashes and street sweepings no expenses are usually given, and the cost will be practically that of collection.

For the disposal of garbage and rubbish some figures are available, although they are not all strictly comparable.

TABLE 12.—Cost of Reduction.

City.	Process.	Date.	Cost to city per ton.	Authority.
St. Louis	Merz.	1897	$1.80	Chapin.
Buffalo	"	1900	0.69	"
"	"	1903	0.77	Local.
Providence	Simonin.	1898	1.62	Chapin.
New York City (Borough of Manhattan)	Arnold.	1899	0.60	"
New York City (Borough of Manhattan)	"	1903	1.71	Local.
Boston	"	1904	0.96	"

Feeding garbage to swine has brought an income in Massachusetts to the cities of Cambridge, Worcester and Brockton, of about 6 cents per capita per annum, Lynn, about 4 cents, and Lawrence and Somerville, about 1½ cents. In New Haven, Conn.,

* "Refuse Disposal and Power Production," by W. F. Goodrich, London, 1904.

the sale yielded 5 cents. The cost of collection in the cities mentioned ranged from 10 to 27 cents per capita per annum.

TABLE 13.—Cost of Cremation, Excluding Interest and Depreciation.

Cremating Garbage and Rubbish.

City.	Name of furnace.	Date.	Cost per ton.	Authority.
Salt Lake City, Utah	Engle	1898	$0.39	Chapin.
Fort Wayne, Ind.	Dixon	1898	0.50	"
Terre Haute, Ind	Brownlee	1899	0.50	"
Richmond, Va.	Engle	1899	0.60	"
Houston, Tex.		1899	0.60	"
Macon, Ga.		1899	0.70	"
Augusta, Ga.		1899	0.80	"
Yonkers, N. Y.	McKay	1900	0.56	"
Camden, N. J.	Dixon	1900	0.73	"
Atlantic City, N. J.	Smith	1901	1.42*	Fetherston.
Minneapolis, Minn.	Decarie	1903	0.38	Local.
Trenton, N. J.	Davis	1903	0.52	"

Cremating Ashes, Garbage and Rubbish.

Montreal, Que.	Thackeray	1901	$0.37	Pelletier.
San Francisco, Cal.	"	1904	0.45	Local.

Cremating Rubbish Alone.

New York, N. Y.		1900	$1.06	Craven.
Boston, Mass.		1903		

* Including interest and depreciation, the figure is $2.47. Probably the best test of a garbage furnace in America was made in Atlantic City.

Dumping on land or into water requires practically no cost but that of collection. For plowing into soil no figures are available.

The cost of the reduction process, from the best available information, is contained in Table 12. The cost does not include collection from buildings, nor the disposal of refuse other than garbage. It is usually fixed by contract.

The cost of cremation is given in Table 13. As in previous cases, it excludes collection and the figures even then may not be on a strictly comparable basis. So far as is known to the

writer, most, if not all, of the cities cremate a combination of garbage and rubbish, and at the cost as given excluding any allowance for fixed charges and depreciation.

Conclusion.

It is hoped that in the foregoing discussion the subject of city refuse disposal in the United States has been outlined in a manner and with sufficient fullness to indicate its present status, the present practise with its merits and defects, and the directions in which improvements are required and indicated.

The collection of the refuse is a comparatively simple matter, the best means for doing this are fairly well known to the profession and the only hindrance to their more general adoption is the lack of local knowledge or funds.

Before the questions involved in the disposal of refuse can be solved in the United States with entire satisfaction, it will be necessary to make some careful investigations, such as have been made in Europe, so as to determine for each class of cities which of the several processes, developed to a satisfactory point, will be the most economical one for the present and future. To aid this work it is also highly important that better statistics concerning the subject than are now available should be recorded.

After years of experience in England, and several careful and thorough examinations and trials made in both England and Germany, the following conclusions have there been reached:

First.—In no European city is the grease sufficient in quantity to warrant the cost of its extraction;

Second.—In England the amount of combustible matter is generally sufficient to burn the refuse and produce steam without the constant addition of fuel;

Third.—In Hamburg the same condition exists; and

Fourth.—In Berlin the refuse contains enough fuel to burn itself during the summer months, but in winter it can only be burned by the addition of coal; sifted Berlin refuse will burn at all times, but not at economical cost. So far as the writer knows, the Berlin refuse disposal question has not yet been finally settled.

The most important questions for solution in the United States now are:

First.—The extent to which reduction works are satisfactory and economical. In the largest of our American cities the amount of wasted fats and oils has been sufficient to pay for extraction. The question yet before us is the limit down to which it will pay, and the lowest profitable price for the grease.

The extraction of grease is but a part of the refuse disposal. There are also other parts, and the further question remains as to the total economy of properly disposing in addition all these other parts.

Second.—The question as to the most effective and economical crematory in order to burn all or some parts of the refuse. In Europe there are several of such refuse destructors which for efficiency and economy have stood the test of years. It is true that they may be less efficient for American refuse. The adoption of the English furnace in Montreal and San Francisco has not met with the same perfect success which is recorded in Europe. Yet the history of American types of furnaces has not been any more encouraging, and in a number of instances even less so. The question of comparative cost, on the basis of both wages and combustibility of material, in Europe and America, also indicates that America has room for improvement in the methods of refuse cremation.

Third.—Present English practise indicates that the utilization of heat from refuse destruction promises to reduce its cost and make the works more efficient. To utilize economically the power in the United States would require the addition of auxiliary grates upon which to burn coal for steaming when the efficiency of the refuse for this purpose falls short. The question arises as to how far this is economically practicable.

Fourth.—The question as to how far the refuse shall be separated and collected in different receptacles, depends on the adopted method of final disposal. The fact that even a large city can change from a combined to a separate system of collection without serious trouble, which is a more difficult change than the reverse, was demonstrated a few years ago by the City of New York. Dependent further on what is to be done with the different parts of the refuse, is the decision as to which parts, if any, can be combined, which decision again determines for each the best intervals of collection.

Fifth.—A decision regarding the most economical final disposal must also depend upon a more accurate knowledge than yet exists of the character, analysis, relative quantities and seasonal variations of the materials making up the refuse.

With the above questions satisfactorily answered, the writer believes that the art of collecting and finally disposing of the municipal refuse of American cities will be materially improved.

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DISPOSAL OF MUNICIPAL REFUSE.

NOTE ON THE REMOVAL AND UTILIZATION OF MUNICIPAL REFUSE IN FRENCH CITIES.

By P. Tur.*

Translated from the French.

It is necessary to try and define what is understood by "municipal refuse;" local customs and regulations being liable to create quite important differences, so that misunderstandings might result because of doubt concerning the kind of refuse considered.

It seems that by giving their broadest meaning to these two words "municipal refuse," they may apply to three kinds of refuse which are kept separate in Paris, that is:

1.—Industrial refuse;

2.—Street sweepings;

3.—House refuse.

The industrial refuse includes in a general way all the waste and refuse produced by the various industries established in cities. The kinds of refuse being as numerous as the industries themselves, it is out of the question to try and enumerate them all.

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They include in all cases the refuse and organic waste from kitchens, restaurants, hotels, schools, seminaries and boarding-houses.

In Paris, the proprietors of industries have to dispose of the refuse produced on their premises. They are prohibited from dumping it on the streets.

This refuse is naturally disposed of in many different ways. Some of it is expensive to remove, for instance, ashes and coal cinders from steam engines have most of the time to be carried to the public dumping places.

The kitchen refuse, on the contrary, is sold at a profit on account of the many utilizable matters which it contains. In this way, more than one housekeeper gets profits from the remnants of her kitchen; otherwise, the rag pickers know how to pick them out from the refuse cans.

It is only some small tradesmen, and chiefly the retail fruit-dealers, who are allowed to drop their refuse on the streets. But these excepted, the city has nothing to do with the removal of industrial refuse. Only the Board of Health has authority to interfere when there is an unhealthy accumulation of refuse.

Since 1873 the sweeping of the streets has been entirely in the hands of the municipal authorities. The property owners are exempted from all work by the payment of an annual tax.

The work begins at 4 A. M. The municipal laborers sweep the sidewalks, and horse-drawn sweeping-machines take care of the roadways. When the weather is dry, the roadway is sprinkled lightly before sweeping. Often, chiefly on wood pavings, the street is washed thoroughly.

The refuse, dust or mud, is brought against the curb in the gutter. These gutters are all provided with running water through hydrants conveniently disposed on the highest ground. As soon as the sweeping is finished, the municipal laborers open these hydrants and wash the refuse by means of running water to the nearest sewer opening.

If the roadway is ballasted, the washing in the gutter must be accompanied by a kind of threshing of the refuse, since only the lighter part goes into the sewer, the heavier part remaining at the bottom of the gutter, where sand is found afterward quite often good enough to be used again for the maintenance of the roadway.

In the afternoon all streets with heavy traffic are swept a second time. If the weather is dry, however, sweeping-machines are not used and the sweeping is done by hand. In streets paved or asphalted, the refuse composed practically of horse manure only, is picked up in wheel-barrows and dumped near a sewer opening from which running water, provided for by hydrants placed under the sidewalks, carries it into the sewers. On the ballasted roadways the horse manure is nearly always mixed with quite an amount of mud; the refuse is then generally piled up in the gutters, or the side of the walk, whence it is carried away every day, by contractors to the public dumping places.

With this one exception, all sweeping refuse is thrown into the sewers; it mixes with the kitchen water and sewage of the private houses and is carried with them to the purifying fields established around Paris.

In the gutters, furrowing these fields, it is frequently observed that the earth takes a kind of felty appearance; this felting, which does not give any serious trouble, is caused, for the most part, by the horse manure coming from the streets.

It is well to insist on the method of disposal of street refuse described above. Paris, so far as is known, is the only place where this system is used. It may not be very economical on account of the quantity of water required, but it gives great cleanliness in a very short time.

In most other French cities, the street refuse is carried away in the wagons which every day collect and carry away the house refuse; both kinds of refuse are generally treated alike, and what is subsequently said in this paper applies to both.

In Paris, house refuse is known as garbage (*gadoues*). A municipal regulation, dated March 7th, 1884, gives its exact definition, and at the same time regulates the conditions under which it is allowed to be placed on the public streets.

The house garbage is composed of "all kitchen refuse and any remnants produced by the sweeping of the inside of private properties or public buildings." It must not be mixed with industrial refuse, earth, gravel, rubbish and all other refuse produced by any repair or other works, or the maintenance of yards and gardens. It must be contained in pails having a maximum capacity of 30 gal., and weighing when empty not more than 31 lb.

Householders must cause these pails to be deposited at the doors of their houses at least one hour before the regular time of removal by the Municipal Department. This removal takes place in summer between 6.30 and 8.30 A. M., and in winter between 7 and 9 A. M.

The broken crockery, glass, earthenware, etc., from private houses are ordered to be deposited in special receptacles. But this rule has never been observed and has been practically given up after a few attempts to enforce it. The same dump-carts used for the disposal of house refuse also remove the market waste; this waste is composed mainly of the same elements as the house refuse, but is richer in vegetable matter.

In most French cities, the house refuse is of the same character as that of Paris, but is mixed at the time of removal with the street sweepings, as before stated.

In many cases it is still permitted to dump the refuse in a heap on the street, but the tendency is to enforce, as in Paris, the use of garbage pails. In quite a number of cities the officials can compel householders to sort the broken glass, crockery, earthenware, etc., which are then removed separately.

In Paris the refuse is removed in large, two-wheeled dumping-carts called "guimbardes," drawn usually by two horses. Their capacity is from 2 to 6 cu. m. These carts are very high and very awkward to load. The loading is done by city laborers but the hauling is let out by contract.

The carts are open on top and only within a few years have been covered by a tarpaulin, too often dilapidated. When they are overloaded and the wind blows, this causes trouble. The organization of this part of the garbage service is as yet rudimentary and quite deficient; it will not be possible to improve it as long as the garbage is carried directly to the fields by the carts which remove it.

The city officials have just ordered a competition in order to choose a more satisfactory type of cart, but no final choice has been made as yet.

Most of the cities outside of Paris use ordinary dumping-carts provided by contractors for the removal of garbage. In only a few cities is the municipal removal in force.

As soon as collected, all the Paris garbage was carried until the last few years, directly to the fields.

The greatest portion was delivered to the farmers from the same carts in which it had been loaded from the streets; another portion was shipped by railroad, and yet another by boats.

Of a total annual quantity of about 600 000 tons, there were:

380 000 tons, or about 64%, carried by horses.

140 000 tons, or about 24%, carried by railroad.

80 000 tons, or about 12%, carried on the Seine, or the canals.

But little by little the contractors who are paid by the city for the removal and disposal of garbage, have raised their bids. The total expenditure for the city, which was about 845 000 francs in 1873, has quadrupled and in 1901 reached 3 435 000 francs. This was due to the fact that the fields, on which it was possible to utilize the garbage, were becoming more and more scarce in the immediate neighborhood of Paris; the suburban towns were refusing to allow garbage to be deposited in their territory and, sometimes, it was not without trouble that the garbage-loaded carts were allowed to pass. Furthermore, the farmers able to buy chemical fertilizers, cheap and easy to apply, were more particular; they were willing to pay only a low price for a fertilizer which required a careful sorting.

Without such sorting their fields were strewn with tin cans, broken crockery and glass, which were dangerous for their horses' hoofs.

It became necessary to think seriously of improving the previous methods.

From 1886 to 1898 incineration systems were carefully studied. After a few trips to England, the municipal engineers built a trial oven and kept it working during the entire year of 1895. These trials have given a number of interesting data. It has been found that the Parisian garbage was self-burning, *i. e.*, that it would burn without any addition of coal. Engineer Lauriol has defined very exactly the conditions essential to obtaining perfect combustion in an oven. But even then the weight of ashes and cinders was nearly 40% of the garbage weight, and as long as a way has not been found to utilize either these ashes or cinders, or the heat produced by the combustion, there is no saving in this method.

On the other hand, the city has received a large number of different proposals which have been studied successively with the

result that only one has been carried out, *viz.*, the agricultural utilization of garbage after grinding.

By this system the garbage is carried to a plant located as near as possible to the centers of removal and reached by a railroad spur and also, if possible, by a water route. The garbage is dumped into a pit from which it is raised by an elevator after a short sorting. From the elevator it is emptied into a grinding-machine formed of two rotating steel-toothed plates, from which it falls into the cars for removal.

This ground garbage looks like vegetable earth mixed with bits of straw and many pieces of paper. Its odor is hardly perceptible, can be endured for a long time, and may be removed almost entirely by sprinkling the loaded cars with lime-water. The ground garbage can be used in the fields without giving the same trouble as the original garbage, all *débris,* troublesome or dangerous for the farmers, having been removed.

The inventors of this method, Messrs. Tenin and Pioger, who have turned their business over to the Société des Engrais Complets, began by building in 1896 a small plant to the north of Paris, in the Station of Saint-Ouen-les-Docks, which has prospered continuously.

The comparison between the respective advantages of incineration and the agricultural utilization of garbage has given rise during these last years to spirited controversies.

The farmers, the agricultural syndicates, and the professors of agriculture have denounced vehemently the importation into France of the English incinerating system. They claimed justly that in agricultural matters, England cannot have the same needs as France.

Some attempts have been made to estimate the amount of wealth destroyed by incinerating the Paris garbage and the amounts have varied from 3½ to 5 million francs.

On the other hand, those who advocate incineration point out that the expense of removing the garbage is greater than its selling price on the fields and that under these conditions, its value in Paris is less than nothing. This has been proved by the indifference of the farmers themselves, who will not take the least trouble to procure this fertilizer. Consequently the City of Paris could

not be expected to support the farmers. Its officials had only to look out for the immediate interests of the city and to find the cheapest and least troublesome method of removing its garbage. In fact, this question of economy, up to the present has been the principal consideration, and will continue to be so for a long time.

Hygienic considerations do not seem to enter into the question of the adoption of one method rather than the other, provided the agricultural utilization does not bring garbage storehouses near inhabited centers. This condition can be easily realized with the grinding process. Furthermore, ground-garbage storehouses are not much more disagreeable than storehouses for many fertilizers, dried night-soil, waste from sugar-houses, etc.

On the other hand, the same quantity of garbage which it takes a large incinerating plant a full day to burn can be ground and shipped in a few hours by a small grinding-plant, and there is no reason why one should be more objectionable than the other to the neighbors. The financial side of the question only remains to be considered, but there is no doubt that the grinding method has a decided advantage over incinerating, and for the present must be given the preference.

The choice to be made in Paris does not depend on theoretical considerations, but on practical demonstration and figures. There is no absolute proof in the matter; there is only the relative proof which may vary, not only in place to place, but furthermore, in the same place, from time to time. When Paris has extended so far that the agricultural fields are out of the question for the disposal of garbage, it will have to be burned. It is also likely that even now, in the countries where there is little farming and where the soil is rich enough to produce without fertilizers, the incineration of garbage is the best way to dispose of it. But omitting consideration of the future, the first thing to determine is the best method of solving the problem for the present.

Consequently, the grinding of garbage, in view of its agricultural utilization, has made considerable progress in Paris during the last few years. Of the 20 boroughs in the city, 11 have given a contract for the disposal of garbage to the Société des Engrais Complets.

Besides the plant at Saint-Ouen, which has been in operation

since 1896, the company has erected a new plant at Issy and contemplates building a third one at Romainville.

Other companies have begun to compete for the same work, and have put in bids to treat by a similar process the garbage of the other nine boroughs.

However, in order to guard against the contingencies which the continued increase in the population of Paris cannot fail to produce sooner or later, the Municipal Government does not lose sight of the question of garbage incineration. An endeavor should be made to install a plant capable of burning the garbage of one borough. This plant should be located inside of Paris, and as near as possible to the center of the borough which it serves, in order to reduce to a minimum the charge for hauling.

It does not seem that other French cities have as yet been forced to undertake experiments like those just made in Paris. Up to the present time, the farmers have taken care of all garbage produced without difficulty or inconvenience. Marseilles, for instance, fertilizes with its garbage the great barren plains of La Crau.

Havre is the only city which has thought of discarding the agricultural utilization of garbage. An inventor, M. Exbrayat, has made a proposal to combine the garbage with coal dust for the manufacture of a rough and cheap fuel. This proposal has been accepted by the city and the plant will be erected in the near future.

At Monaco, where agricultural cares necessarily give way to the entertainment of tourists, incinerating ovens of the Horsfall system have been installed during the last few years.

This paper would not be complete without a few words concerning the rag pickers whose existence in Paris has always complicated the study of all questions pertaining to house refuse.

The rag pickers of Paris form a population, of which one part is fixed and the other, nomadic; with the women and children, they are estimated to number from 20 000 to 25 000 persons, according to a recent report by M. Mazerolle.

The rag picking is done first in the houses; rag pickers called "placiers" or "ilotiers," from the place or block where they are known, are authorized by janitors to take the garbage pails from yards of buildings and carry them to the sidewalk from which place

the street cleaners empty them into the dump-carts; they get from these garbage pails, the first and generally a satisfactory collection. A number of other rag pickers are authorized by the city to climb on the carts and to pick out, at the time during which the pails are being emptied, any thing of use which has been left. Still another sorting by the rag pickers is allowed, in stations and at the gates, at the time of the trans-shipment of the garbage.

In the grinding-plants the same practise is followed when the refuse is dumped into the pits, and from the pits into the grinding-machine. The installation of the plants makes the work comparatively easy for the rag pickers.

The rag pickers are always interested in all improvements made by the city for the disposal of refuse, fearing that their occupation will be injured for the benefit of some contractor. At different times, their protests have been strong enough to stop improvements requisite for the public health.

It is to be hoped that the building of new grinding-plants, where all facilities are offered for sorting garbage, will modify, little by little, the old privileges of the rag pickers.

There are in France, outside of Paris, few large cities which have rag pickers, and in these their number is always quite small, and they do not assume the same importance as in Paris.

The objects sought by the rag pickers in Paris are the same as those sought by rag pickers all over the world, *i. e.*, rags from wool, linen or cotton, old paper, bones, leather, white glass, tin cans, sheet iron, pieces of bread, orange peel, snail shells, etc. The value of these various objects has been decreasing for a number of years, and in the near future, it is more than likely that the rag-picking industry will have to submit to important and lasting improvements.

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DISCUSSION ON
DISPOSAL OF MUNICIPAL REFUSE.

By Messrs. W. Francis Goodrich, M. N. Baker, Shirley C. Hulse, Andrew Rosewater, Robert Spurr Weston, George W. Fuller, Gardner S. Williams, L. J. Le Conte, J. C. H. Stut, Ed. Vermehren, Bohm and Grohn, G. Watson, Rudolph Hering and P. Tur.

Mr. Goodrich.

W. Francis Goodrich, Esq., London, England. (By letter.)—Mr. Hering's paper, while being valuable as an exhaustive discussion of the present position of American cities in regard to final and sanitary refuse disposal, cannot be but disappointing to the British sanitarian.

In dealing with some few points in Mr. Hering's paper, the writer would like to have it clearly understood at the outset that, while some of his remarks may appear to come from an extremist, he is but discussing the matter from the standpoint of final and sanitary refuse disposal, as it is now generally accepted in Great Britain.

Speaking generally, there is abundant evidence in Mr. Hering's paper that he is not in touch with modern British practice. This is unfortunate inasmuch as it has led him to mere negative conclusions, while a more intimate acquaintance with recent British practice would inevitably have led him to look more hopefully upon the possibilities of power production from the cremation of combined American waste.

Mr. Hering states that the greatest heat developed with British destructors ranges from 1 500 to 2 000° fahr. This is a mistake; with well-designed modern destructors a temperature of 2 000° fahr.

Mr. Goodrich. is now quite common, and temperatures of 2 500° and even 3 000° fahr. are frequently reached, while a temperature of 1 500° fahr. may be taken as the minimum temperature during the clinkering of the fires, or at times of only partial activity in the cell.

Again, on page 281, Mr. Hering records some very satisfactory results obtained with destructors for burning rubbish in Boston and New York. Now, New York rubbish, as defined in Table 3, does not contain any cinder or recoverable coal, and with these valuable constituents missing, it must be admitted that the results obtained in power production are very good, and, as such, are not in harmony with Mr. Hering's conclusions. It may be reasonably asked what evaporative efficiency would have been obtained had the calorific waste not been extracted, and again would not such a result have very clearly demonstrated the value of such combined waste, and the absurdity of sorting?

Mr. Hering does not appear to regard unfavourably the feeding of garbage to swine, and apparently this is largely practised in New England cities. Such a practice clearly involves (1) a daily collection; and (2) careful sorting. A daily collection is costly and very often impracticable, and it is not too much to say that it is unnecessary, unless, of course, the garbage be destined for feeding pigs, and viewed from this standpoint such material need yield a good revenue. In Great Britain, it is quite impossible for any municipality to start a piggery, and thus dispose of their garbage; it is almost impossible for any private individual to embark in the business; public opinion is against such a method of disposal, and every sanitarian and medical officer of health is opposed to it. Are we in Great Britain wrong, or is it that the American standard of sanitation is low? Personally, the writer has no hesitation in stating that the feeding of garbage to swine is a wretched practice. It may be defended from an economic point of view, but it is open to grave abuse; it may involve serious consequences, and it is not worthy of a great people in the twentieth century.

Some years ago the refuse in many parts of Great Britain was readily taken by farmers and utilised for manurial purposes. In not a few towns the refuse was thus disposed of with but little trouble and at a small financial gain, the farmer paying for it. Now, generally speaking, farmers will not take refuse, even if they are paid to accept it. Briefly, the reasons are as follows: (1) The changed composition of the refuse, the considerable proportion of tins, pots, metal and a great variety of material which has no manurial value; (2) the cheap artificial manures offering, most of which are of known composition and have a definite value. A ton of artificial manure has a fixed value, the farmer knows what he may expect; on the other hand, a ton of refuse is an unknown

quantity; unsorted, it is most certainly unfit for the land, while it cannot pay either the municipality or the farmer to sort refuse for manurial purposes. Mr. Goodrich.

Mr. Hering appears to regard favourably the disposal of refuse by dumping into water, providing proper precautions are taken. It would have been useful had Mr. Hering told us what may be deemed proper precautions. It has been understood that all that can be done in this direction is to obtain accurate knowledge of the tides and send the refuse sufficiently far out to sea to ensure its non-return, but where has this been accomplished? And why is it that so many towns on the English seaboard cease to send their refuse to sea and erect destructors instead?

The reason is not far to seek, for, despite every precaution, sea disposal has been a dismal failure. Take, for instance, one case, the City of Liverpool. Mr. G. F. Deacon, at one time City Engineer, made an exhaustive personal study of the tidal conditions at varying distances up to 20 miles out from St. Georges Pier, Liverpool. He inaugurated an elaborate system of sea disposal which at a later date was perfected by the present City Engineer, Mr. J. A. Brodie. Manual labor was to a large extent displaced by ingenious mechanical devices, and the Liverpool system was, beyond question, more economical and satisfactory than any system of sea disposal yet devised.

Ten years ago, Mr. Brodie in a paper read before the Sanitary Institute Congress at Liverpool stated that disposal at sea was unquestionably the most satisfactory and economic method of disposal for the refuse of such districts of Liverpool as are in close proximity to the docks. To-day, six large destructors are working in the City of Liverpool, and the power is mostly used for purposes of electric traction.

Liverpool refuse, in spite of every reasonable precaution, was deposited on the beaches of North Wales seaside resorts. The Local Government Board when approached by any municipal authority on the English seaboard for sanction to borrow money for the purchase of hoppers for sea disposal, requires an undertaking from the authority that the refuse sent out to sea shall not return and so cause offence to other towns on the coast. Recognising the impossibility of giving such an undertaking, disposal at sea is no longer considered as a feasible system of disposal by English seaboard towns; it is doomed and will, at no distant date, be abandoned by the few towns using it.

It is undoubtedly cheaper to purchase the necessary hoppers than to provide a destructor; the standing charges are also less, especially if it is not possible to utilise the power available from the refuse if destroyed; but economy is only one factor. First, a satis-

Mr. Goodrich. factory system of final disposal is demanded, the economic factor is a secondary factor.

A town on the eastern seaboard, *A*, is provided with a destructor; the towns of *B* on the north and *C* on the south send their refuse out to sea, the beach of *A* is defiled with the filth from *B* and *C*. This is a typical case on the northeast coast of England, and is it to be supposed for one moment that with examples of this kind before it that the Local Government Board will any longer countenance disposal at sea? It has had a long trial under a great variety of conditions; it has an unsatisfactory record and not in Great Britain alone; it will as surely be displaced by disposal by fire as night follows day, and the time is not far distant.

Even as the dumping of refuse into large volumes of water is doomed, so far as Great Britain is concerned, so is the dumping of refuse on the land. Like the United States, we have hundreds of these monuments of municipal wisdom all over the country. Within the past two years an ominous precedent has been established by the Local Government Board, in the case of two well-known English towns, whose applications to borrow sums of money for the purchase of land for tipping refuse on were declined. The Local Government Board in refusing to sanction such loans recommended the adoption of refuse destructors instead. It will thus be evident that the attitude of the Local Government Board toward both tipping on land and at sea is such as to discourage any method of disposal but that which is beyond question final and sanitary, *i. e.*, disposal by fire. It is no mean tribute to modern destructor practice for such a notoriously conservative body as the Local Government Board to take such a definite stand.

Dr. Woodbury of New York has been credited with stating that the separation of waste in New York was only secured by the active aid of the police. If the waste is not separately deposited by the citizen, sorting is essential if a municipal authority decide to separate and classify waste for disposal in various markets. The British sanitarian views with alarm and disgust the sorting of waste as practised in New York and other American cities. It is true that the United States may have the best case from the purely economic standpoint, but then it must not be forgotten that the waste is to a large extent sorted by the citizen. If the citizen does not separate the waste, the sorting process is abominably filthy and by no stretch of the imagination can it be deemed a sanitary or final process.

For some years the sorting of refuse for profit excited bitter indignation in London. The pictures which have been published of the old sorting wharves indicate conditions no worse than those depicted in photographs taken in New York, it is a system inde-

scribably filthy and moreover unnecessary. In London it has practically come to an end, and outside of London it is unknown in British cities. Only one of the metropolitan boroughs, *viz.*, Lambeth, continues to sort refuse. Extracts from a recent report of Dr. Priestley, Medical Officer of Health to the Metropolitan Borough of Lambeth, are appended: Mr. Goodrich.

"The whole process is an exceedingly offensive one, and most degrading to the workpeople employed in it, especially the women and girls, who are to be seen standing with the refuse up to their waists, if not higher, whilst the foul odours which are given off during the process of sorting and also from the heaps of refuse awaiting sorting, may, and often do, become a nuisance to the surrounding neighbourhoods.

"It is an anomaly, if not a disgrace, that the wealthiest corporation in the world should persist in carrying out what is recognised by all sanitarians to be a most noxious and degrading business, and as such business is carried out in the parish of Lambeth, I feel it my duty to report strongly in connection with the matter."

There are few sanitarians in Great Britain who have studied the sorting process so closely as Dr. Priestley, and his conclusions carry considerable weight. A policy of sacrificing financial gain it may be, but, of the sanitary gain, there can be no question.

On page 289, Mr. Hering, in quoting from an earlier paper, seeks to prove that American crematories have failed because they have been provided with horizontal instead of sloping grates. There is but little, if indeed anything, in this; in the best modern British practice, the grates are but very slightly inclined from the horizontal. Further the separate drying hearth, alluded to by Mr. Hering, has been discarded long since with at least two types of English destructors.

Mr. Hering is also wrong in stating that "the expert garbage fireman * * * is considered essential to success in England." As a matter of fact, many of the most successful destructors in England are being run by "firemen" who have had no previous experience. Men of experience are, as a rule, a class to be avoided, they have too much to unlearn; the valuable man is generally the man who knows nothing about firing and knows that he knows nothing, he is then likely with experience to develop into a good fireman.

Mr. Hering's description of the Meldrum destructor is inaccurate in so far as the reference to the escaping gases is concerned. There are no baffle pillars of any kind, the hot gases in leaving the cell merely pass over a bridge into the combustion chamber which is always arranged between the destructor cell and the steam boiler.

Likewise, the Beaman and Deas type of destructor is wrongly

Mr. Goodrich. presented; there is not, nor has there ever been, a self-feeding open hopper in connection with this destructor. Martens patent direct-charging hopper has been applied in connection with this type of destructor in a few installations, but this hopper is not self-feeding or in any way automatic in action.

It is interesting to note that refuse is burned in the heap in the open air in a few cities in the Southern States. To claim that such a method of disposal is satisfactory would seem to indicate that the wish is father to the thought. Generally speaking, it is regarded as a public nuisance in Great Britain, and every action which has been taken against offending parties has been successful.

A rather extraordinary statement may be found on page 297. Mr. Hering mentions that, "there are furnaces with natural draft, with forced draft and with steam-jets." As a matter of fact, in modern destructor practice we have only forced draft; the natural-draft destructor is obsolete, and need not be taken into account. Forced draft is provided either by centrifugal fans driven by steam or electricity, or by steam-jet blowers. Steam-jets, needless to add, are in themselves of little or no use for draft production. Steam-jet blowers are used in connection with over 70% of the destructor installations in Great Britain.

Mr. Hering is again in error when he observes that, "steam is forced under the grate in the Horsfall furnace, and air in most of the other English furnaces." With every modern destructor in England, air is used for forced draft, the difference between the various types of destructors being that some use the steam-jet blower to deliver the requisite air supply, while others use centrifugal fans. Horsfalls and Meldrums both use steam-jet blowers in England, and the great majority of destructors erected in Great Britain are of these makes.

There are many errors in the paper by Mr. Hering which the writer is compelled to pass over in the wish to be as brief as possible. The paper simply teems with misstatements concerning English destructors, and to this lack of knowledge of English practice, the negative conclusions presented by him may be largely attributed.

Mr. Hering states that present English practice indicates that the utilisation of the available power from refuse promises to reduce working cost and make for efficiency. This statement altogether fails to convey anything like an accurate idea of the present practice in Great Britain.

When something like 100 destructors are supplying power for electrical purposes, sewage pumping or water pumping, which work would have involved the use of 150 000 tons annually of the best steam coal, it is idle to talk about promise. This is actually being

done, and the working cost is undoubtedly reduced all round wher- Mr. Goodrich.
ever the power is utilized.

Further, as the writer has again and again pointed out, such combined works are more efficient than works where the power is not utilized, inasmuch as the high temperatures which are essential for satisfactory power production are at the same time a guaranty against nuisance.

Mr. Hering appears to favour exhaustive analyses of refuse with a view to the compilation of data as to the actual composition of refuse at the different seasons. While admitting that all these data would be serviceable, it must not be forgotten that in every center of population the habits of the people are ever changing, and the waste material is accordingly constantly changing in its composition.

A man may spend a lifetime in the compilation of such analyses, but where will it lead him, and to what extent will it help in solving the particular problem with which he is confronted? Personally, the writer cannot see what can be gained thereby. Our present position in Great Britain has not been attained by such methods, and when the writer speaks of the present British practice, he refers not only to the very considerable number of destructors operating in Great Britain, but to those of similar design which are successfully dealing with such varying classes of waste as are found in South Africa, Australia, France and Belgium. Our present position in Great Britain is due only in a very small degree to analytical work, but in the main to a clear appreciation of the cardinal principles of combustion and a great deal of practical experimentary work, without which all analytical data would be worthless.

On page 307, Mr. Hering observes that the furnaces of English design erected at Montreal and San Francisco have not been so successful as in Europe. What are these so-called English furnaces which have been erected in Montreal and San Francisco, why are they termed English furnaces, and why have they not given complete satisfaction?

First, their only claim to the word, English, is because they were erected by a company employing an English engineer, Thackeray by name; secondly, these so-called English furnaces are simply a poor imitation of the original Fryer destructor of 20 years since. Why have they not given complete satisfaction in America? The reason is not far to seek; an imitation of that which failed to satisfy in England 20 years ago is scarcely likely to satisfy in American cities to-day, and that which failed to destroy satisfactorily English refuse, even in towns where the refuse was of good calorific value, cannot reasonably be expected to destroy perfectly the waste of two such cities as San Francisco and Montreal.

The writer has not the slightest hesitation in saying that the

Mr. Goodrich. best modern British destructors would deal quite successfully with the combined waste of American cities, but, while there is a keen appreciation of the value of many American inventions in Great Britain and an ever-increasing desire upon the part of the British engineer to adopt ingenious American devices and thus profit by experience gained in America, it would appear that British destructors and experience which is at the disposal of American engineers do not commend themselves to them.

Is it a feeling of humiliation, or is it prejudice which holds them back? Whatever the reason may be, rest assured, first, that the loss is their own; and, secondly, that whether they elect to try British destructors or not they will only solve the problem by proceeding upon such lines as have led to success in Great Britain.

Mr. Baker. M. N. Baker, Esq., New York City. (By letter.)—Mr. Hering's paper surpasses any previous American paper on the subject. The analytical and comparative figures of the composition of municipal refuse in the United States and Great Britain and of the cost of refuse disposal are particularly noteworthy, but it must be said that some of the figures, although the best attainable, are based on such meager records as to be of doubtful value except in a most general and tentative way. It is unfortunate that so few reliable figures showing the composition of American municipal refuse month by month through a period of years are available. The British figures are also scanty enough.

From a visual inspection of the refuse being consumed by nearly two score British refuse destructors in the spring of 1904, the writer is of the opinion that the average British refuse contains less garbage proper than is indicated by the figures given in the paper, but he acknowledges that visual inspections are likely to be deceptive and is aware that much more green stuff is taken to the destructors in summer than in the winter and spring.

It is gratifying to see that Mr. Hering raises no vain hopes regarding the possibilities of obtaining power from American municipal refuse. Undoubtedly, however, some of the British authorities on refuse disposal will argue from the figures of composition presented in the paper that the American people are not showing their usual alertness to utilize by-products when they fail to combine refuse destructors with electric and other power stations. Such combinations are even more common in Great Britain than Mr. Hering indicates, but few detailed figures are as yet available to show whether or not such combinations are really worth while.

Mr. Hering very properly emphasizes the need of considering refuse disposal as an engineering question, which has seldom been done in America. It is to be hoped that his paper will be the means of hastening the day when some large city will take up the problem

from that point of view, giving due consideration, as he suggests, to the sanitary and economic possibilities of garbage reduction, the adaptability of British furnaces to American refuse, the utilization of heat, and the relative advantages, where cremation is practiced, of dealing with separated and with mixed refuse. Mr. Baker.

Shirley C. Hulse, Jun. Am. Soc. C. E., Ithaca, N. Y.—The speaker would like to say a word with reference to the possibility of making garbage burn itself. Mr. Hulse.

During the Ithaca typhoid epidemic in 1903, George A. Soper, Assoc. M. Am. Soc. C. E., at that time representative in Ithaca of the New York State Board of Health, recommended that the city garbage be otherwise disposed of than by dumping in outlying low ground—the established custom of the city. Under the existent conditions, the problem demanded a quick and inexpensive solution, and this was had in the repair and use of two fire cells of an abandened tannery. These cells, each about 6 ft. high, 4 ft. wide, and 10 ft. deep, were fitted with grates of old rails and were connected by a 24-in. sheet-iron pipe, 50 ft. long, to a brick stack some 75 ft. high and $2\frac{1}{2}$ ft. sq. inside. This plant which certainly bore little resemblance to a properly designed garbage destructor gave surprisingly satisfactory results. Accurate records of quantities and composition of the materials destroyed are unobtainable, but the City Superintendent is authority for the statement that the plant was in operation for 8 months, that it handled some 14 two-horse wagon-loads per day, that not more than 20 cords of wood all told were used to assist in the burning, and then only when the material was wet.

The speaker can vouch for the fact that when the plant was first put in operation, it handled from 6 to 15 loads per day—running mostly 24 hours—and that wood and a little kerosene were added only occasionally when the garbage was wet. It may be further stated that the material burned was not properly freed from ashes and other incombustible refuse; that it contained large quantities of kitchen wastes from the many student boarding-houses; and perhaps a proportionate quantity of old barrels, boxes and papers which latter of course greatly facilitated combustion.

The performance of this emergency plant in handling the refuse of a university town of some 15 000 people would seem to indicate rather favorably the self-destructive possibilities of garbage.

Andrew Rosewater, M. Am. Soc. C. E., Omaha, Nebr.—Mr. Hering is entitled to a great deal of credit for having collected the data which form the basis of certain features of garbage disposal. About 15% of the cost of the disposal of house waste is embodied in its treatment, and 85% in its collection and haulage to the point of disposal. Mr. Hering dwells upon the 15% of the expense, but Mr. Rosewater.

Mr. Rosewater. seems to ignore the 85% upon which the sanitation of cities is largely dependent. The failure of collecting garbage in cities and its proper disposal are largely due to failures in police regulations —failures in municipal governments to consider properly the question of public interest from a sanitary standpoint.

There are quite a number of cities in the United States, among them Washington, that collect their own garbage and dispose of it. Washington spends about $58 000 to $60 000 per annum for the disposal of its garbage. This includes the collection which represents the greater part of the cost. Wherever cities undertake, as they do in Europe, the collection as well as the disposal of garbage, they solve the problem to a greater degree from a sanitary point of view than is possible under separate collection and disposal.

As has been stated, garbage is disposed of in the United States very often by dumping into the rivers and harbors, and unquestionably in a large majority of cities where garbage disposal is conducted under contract by the cities, it is done in that way. It must be conceded that such methods are unsanitary, even if the garbage is thrown into large rivers. Wherever cities fail to collect the garbage themselves, the garbage in the poorer districts is scattered in the alleys simply because the people cannot afford, or are unwilling, to pay the charges made by private individuals for the collection, so that the solution of garbage disposal is more largely dependent upon municipal collection that upon any special form of incineration. If private individuals are allowed, as is done in most cases, to collect the garbage and charge a fixed price for doing so, the effect is that the poorer classes and others disposed to dodge the expenditure, will throw the garbage upon the streets and alleys, which results in offensive and unsanitary conditions. Therefore, the first solution of this problem lies in the direction of municipal rather than private collection.

The speaker's personal observations in the City of Omaha have satisfied him that the drift of effort has always been to feed hungry contractors who manipulate the municipal government in order that they may fatten upon what there is to be secured from this garbage matter, rather than to promote sanitary methods of garbage collection. In the City of Omaha, in 1903, we could have disposed of the garbage at an expense of probably $1 000 by dumping it into the river at an excellent dumping place, and yet, through the efforts of individuals interested in city contracts, it costs the city $5 000 per annum, which is paid them for the privilege of using a more objectionable locality under the contractor's control. That is the experience of a large number of cities in this country, and, therefore, it is just as much the engineer's duty to direct public attention to the importance of handling these problems from the broad standpoint

of public health, as it is to study the minor questions of garbage combustion. Mr. Rosewater

From the statistics presented by Mr. Hering, two-thirds of what we call garbage waste in the cities consists of ashes; there is, therefore, but 33% left of what can be called garbage proper. In that 33% there is a large amount of paper and other waste that is combustible, and it is safe to assume that 25% of the total garbage waste is really garbage that contains putrescible matter. Not more than 5% of all the so-called putrescible waste is solid, the remaining 95% being water, and that is what gives trouble in the incinerating process. Instead of seeking to solve the problem of evaporating this 95% of the 25% of garbage by some suitable furnace, it would seem that the simpler way would be to press this 95% out of the garbage, allowing the liquid to escape directly into the sewers, and then utilize the 5% of solid matter of the 25% or 1¼% of the total garbage in combination with the other 8% of combustible material, or treat it as waste to be readily hauled away. Haulage which is an important factor in the expense account of garbage collection can be reduced nearly 24% by pressing out the liquid from the putrescible waste. Independent of this, it also comprises by far the costliest part of the garbage-collection expense. It is usually comparatively inexpensive and easy to haul away and dispose of the ashes which comprise 67% of house waste, as they can be used to fill up low lots and grounds, and at no time do they develop as a nuisance.

Robert Spurr Weston, Assoc. M. Am. Soc. C. E., Boston, Mass. —The speaker would like to say a word in defence of the method of garbage disposal by feeding to swine, especially where fresh kitchen refuse is obtainable. It seems that the disposal of garbage or swill by this method depends largely for its success upon the careful supervision of details. It is analagous to concrete-steel construction, which, when well carried on, is admirable, but when the concrete work is badly done, is the worst construction imaginable. Mr. Weston.

It seems also that the decision to use this method should be determined by the methods used for the collection of the garbage. If the garbage is brought to the swine in a fresh condition, it is possible to keep the drove in a good physical condition, and it is impossible to understand how the use of swine for this purpose can affect the breed of hogs, if no animals are sold for breeding purposes.

The speaker has had to deal with the garbage disposal problem in connection with a large sanatorium for tuberculous patients which has a population of 200. After considering the use of a small crematory, or the burying of the garbage, it was decided that it was wasteful to throw away so much good table refuse of high feeding value when animals could dispose of it at a profit. The

Mr. Weston. meat of the animals is sold, but for two or three weeks before killing, the animals are fed on grain. Careful post-mortem examinations of the swine have failed to disclose any lesions due to infection. This experience coincides with that of other corporations using the same methods.

The collection of garbage for feeding swine is contingent, even more than in the case of collection for disposal by incineration, upon the care used in sorting it. The occurrence of a large percentage of coffee grounds in garbage certainly affects the health of hogs to which it is fed, and the presence of broken glass and china has often caused physical injury.

Just how far this simple, economical method can be expanded so as to include our cities is a question which has been clearly emphasized in Mr. Hering's excellent paper. It is a problem of locality, rather than one which admits of a general solution.

Mr. Fuller. GEORGE W. FULLER, M. AM. SOC. C. E., New York City.—There is one point in municipal sanitation which is of considerable importance and interest to engineers, and which seems to fall between the scope of a paper on the disposal of municipal refuse and one on sewage disposal, and this is the care and removal of the contents of privy vaults and cesspools.

While the removal of that type of waste is, of course, normally done by water carriage in sewers, it is well known that sewers are not extended so as to keep ahead of the growth of American cities. In fact, a large number of the cities in this country have only about two-thirds of their population connected with sewers, and there are some instances where the portion provided with them does not exceed one-half of the total population.

Some six years ago, at the time of the Spanish-American War, a great deal was said with reference to the transmission of typhoid fever by flies. Unquestionably fecal discharges are carried by them to the table in some instances, and in that way there is brought about an infection of the food of people who are, in other respects, surrounded with first-class sanitary works, including the public water supply.

From evidence available, it appears that many American cities will not, for some time, have the low death rates from typhoid fever which are experienced in Europe, even when they are provided with filtration works or ground water, so as to give them practically perfect water supplies.

The evidence further indicates that uncovered and unscreened privy vaults and cesspools have, at times, a very material influence upon the typhoid fever death rates, not only in rural communities and the portions of cities where those conditions obtain, but also in other portions of cities to which flies may transmit infected material

from a distance. This aspect of municipal sanitation is worthy of more attention than it has yet received from sanitary engineers. Simple remedial measures like the universal use of screens to prevent flies from reaching the contents of privies and cesspools would save each year the lives of hundreds of persons who now die of typhoid fever in unscreened districts. Mr. Fuller.

Referring to the garbage disposal question, a reasonably comprehensive knowledge of the kind of municipal refuse disposed of is essential for a fair comparison of the methods of disposal in various cities. The absence of data, showing the individuality of various plants as to the work they have to do, will continue to cause widely different opinions on some aspects, just as has been the case with water purification and sewage disposal methods where only general views and not precise data are involved.

Gardner S. Williams, M. Am. Soc. C. E., Ann Arbor, Mich.— Prof. Williams.
The speaker would most heartily endorse the sentiments of Mr. Fuller in regard to the care of privy vaults and places for the deposit of excrementitious material. The agency of the fly in the transmission of intestinal diseases is to-day demonstrated by more direct evidence than is the agency of water in the dissemination of typhoid, though the latter is far beyond the realm of doubt.

L. J. Le Conte, M. Am. Soc. C. E., Oakland, Cal. (By letter.)— Mr. Le Conte.
Economy and sanitary efficiency are the two main things to keep constantly in mind in the disposal of municipal refuse. Experience everywhere seems to show that forced draft and high flue gas temperatures are absolutely necessary in order to insure the proper consumption of deleterious fumes. In large cities where it is entirely practicable to sell steam power for various purposes, it therefore becomes economical to make use of the waste heat in the flues and to erect suitable boilers to furnish steam for power purposes. Quite a revenue may be derived from this source, which, in some cases, may materially reduce the cost of cremation.

It is a curious fact that American crematories continue to use large percentages of fuel to assist in burning the refuse, if we are allowed to except San Francisco and Montreal, which have the English type of furnaces. But even with the best design, good results cannot be obtained without good management, and under very bad management the best design may bring forth the worst results. Hence it is true that good sanitary results demand intelligent supervision in every stage of the operations. The Thackeray furnaces at San Francisco are practically all right, from an economic point of view, namely, about 45 cents per ton, but are not up to the standard in a sanitary sense; that is to say, the main flue temperature is entirely too low; so much so that the auxiliary boilers cannot get up more than 10 lb. of steam. The boilers, therefore,

Mr. Le Conte. are of no use. The main trouble with the plant is that the features of natural draft and high stack are both obsolete. What is really needed is a forced-draft apparatus, whereby the temperature of the gases in the main flue would be so elevated that high steam could be easily raised on boilers, and the deleterious gases now escaping from the stack be properly consumed. To insure this result, the flue gas temperature should approach 1 500 to 2 000° fahr.

Garbage reduction works as a rule are not to be recommended from a sanitary point of view. They are universally condemned as an intolerable public nuisance. From an economical point of view they are also wanting, the average cost of reduction to a city being $1.16 per ton, and rarely less than 70 cents. With this record before us, it is hard to see how they can hold their ground in the financial struggle for economy and efficiency.

The larger percentage of garbage in American refuse suggests the possibility that a separate treatment of the garbage might lead to a more economical disposal. The experience at Boston and New York, however, seems to put a quietus on this theory, garbage reduction being $1.09 per ton, and rubbish cremation, $1.06 per ton; so that no economy seems to be obtained by separation of the refuse.

The experience all over England and the Continent of Europe is universally to the effect that cremation is the simplest and best solution of the problem of disposal of municipal refuse. The latest improvements in Horsfall furnaces are very important from a sanitary as well as from an economic point of view.

The American furnaces with their two or three coal fires to consume the fumes, and natural draft and high stacks, are certainly an anomaly. What surprises the writer most is that it does not cost more than 63 cents per ton for cremation. This certainly does not include interest and depreciation.

The Hamburg plant cremates the refuse at a cost of 30 cents per ton, after deducting revenues. Any one contemplating building a refuse destructor will do well to study the plans and details of these very complete works. The economic features have been carefully worked out in every detail, and are based largely on long experience, and seem to result in great efficiency from a sanitary point of view.

Mr. Stut. J. C. H. Stut, Esq., San Francisco, Cal. (By letter.)—The writer would like to express his appreciation of the amount of real, hard work that must have been spent on this paper in collecting, sifting and arranging the scattered ideas and publications on this subject, for it is no easy task to arrange and tabulate the different items, especially, as Mr. Hering has not only treated his subject from an American Engineer's standpoint, but has also included the destruction of refuse as carried on in some European countries, thus presenting a broad view of this question.

Mr. Stut.

We have in San Francisco one of the English type of cremaories, which is operated by a private corporation. The cremation of the refuse and garbage, as carried on here, has been very unsatisfactory, and not as it should be, for a very large volume of dense fumes and vapors coming out of the high chimney can be seen every day of the year. These vapors are very obnoxious to the inhabitants of some parts of the city.

In order to understand the nature and character of the material that is delivered at the crematory, and which must be cremated, the writer will cite the following from the municipal ordinance granting the right to cremate the same: "house refuse, butcher's offal, garbage, putrid or stinking animal or vegetable matter, refuse, ashes, dirt, cinders, sludge, crockery, tins, bones, and other like matter, fish, flesh and food condemned by the Board of Health, as unfit for human food, etc."; in short, anything and everything that is thrown away by the inhabitants of a great city including street sweepings.

It will be seen from this that a crematory receiving all these different materials for destruction must have qualifications of a nature that need not be so good as is the case where these diverse materials are segregated in classes, and as indicated by Mr. Hering.

Mr. Hering has stated very tersely the essential qualifications of firemen, and the conditions that must obtain in a first-class crematory, to consume and reduce the several organic and inorganic compounds to their original elements, *viz.*, carbonic acid, water, nitrogen, ashes and clinkers.

In order to do this, the main and essential object must be to obtain as high a temperature in the furnace as possible, so that a fractional distillation or sweating process is not carried on, because it is from this that the fumes and obnoxious gases result, but the temperature must be so high that all the organic compounds are broken down, and no obnoxious gases can possibly result. The character of the material renders it necessary to obtain a high temperature to effect proper combustion.

The English furnaces erected in San Francisco cannot accomplish this purpose, because an abundance of cold air is rushed over and through the garbage in the furnace, which has a decidedly cooling effect; furthermore, the cooling gases from this sweating and smoking garbage are led into a large flue which connects with a 250-ft. chimney, thus creating a very strong draft.

These English furnaces are 8 ft. wide by 12 ft. long, with inclined grates. The garbage is fed into a large cast-iron hopper at the rear of each furnace, and from this the green, wet garbage is raked on to the grate; whereas, alongside the mouth of the hopper, where it empties on the grates, and on each side of it, openings are provided to lead the steam and all obnoxious gases, arising from this

Mr. Stut. only partially heated material, directly into the chimney flue, preventing thereby any thorough combustion, which is absolutely necessary for material of this kind.

After a great deal of study of the subject of so cremating material of this kind that it be thoroughly burned without giving any obnoxious smell, the writer has succeeded in constructing a furnace that gives the desired high temperature necessary for a thorough combustion, and, at the same time, has used this high temperature and the available heat for the production of steam, and this without the addition of any fuel beside the garbage itself.

This furnace retains the hopper in the rear, as described above for the English furnace, also the inclined grate, but the gases arising from the sweltering garbage are not allowed to reach the flue and chimney directly, but are directed from the rear of the hopper to the front of the furnace and over the very hot fire, resulting from the burning garbage.

In the arch at the front, and over the inclined grate, are numerous small openings in the brickwork, and through this hot brickwork all the gases that come from any part of the material must pass. After passing this checker-brickwork, the gases enter a combustion chamber, which is also composed of brickwork; from this combustion chamber, they pass a damper, also of fire-brick and strike directly against the undershell of a large boiler; they pass under and to the rear of the boiler, and at the rear they pass through a number of tubes again to the front of the boiler. Here they rise and are led over the boiler to the rear, where they pass all around the cast-iron hopper at the end where the garbage enters, giving off some of the heat, that may still be in the gases, to the fresh, green garbage which has just entered the hopper.

By this means all the garbage is thoroughly burned, and, at the same time, a great deal of steam is produced from the heat thus obtained, without any other fuel than that contained in the garbage.

From a long experience with these furnaces, it is found possible to produce from 800 to 1 000 h. p. from the use of the garbage that accumulates in a city like San Francisco.

From this it will be seen that the garbage of a city of any considerable size can be cremated successfully, and, at the same time, produce quite a large income.

Mr. Vermehren. Ed. Vermehren, Esq., Hamburg, Germany.* (By letter.)—The works for destroying the refuse of Hamburg have been established for almost ten years, and the system has proved itself very satisfactory, so that further extensions are being considered. The works were fully described by the late Chief Engineer, Mr. F.

* Oberingenieur der Baudeputation.

Andreas Meyer,* in 1901, and since that time the establishment has been still further improved. Mr. Vermehren.

In Brussels, Frederiksberg, near Copenhagen, Zurich and Wiesbaden, destructors have been erected, and in Kiel, Frankfort a/M. and Cologne, it is expected that destructors will be built during 1905.

MESSRS. BOHM† AND GROHN,‡ Berlin, Germany. (By letter.)— The writers have carefully studied Mr. Hering's paper, and with a lively interest have taken cognizance of the present state of the question in America. They agree with Mr. Hering in the opinion that the question of removing and disposing of municipal refuse cannot be solved according to one method for all countries, but that the very different conditions of each must be considered in any endeavor to promote an improvement in this matter. Messrs. Bohm and Grohn.

Without entering upon the details of the paper, the writers feel obliged to say that in their opinion the extensive notes and elaborations given by Mr. Hering treat of the subject so comprehensively that by it a new and excellent foundation has been created for future work in this important branch of engineering. They also thoroughly endorse the conclusions stated at the end of the paper.

G. WATSON, ESQ., Leeds, England.§ (By letter.)—In his paper, Mr. Hering does the double work of instructing his countrymen as to the progress made in regard to the burning of town refuse in Europe, while, at the same time, he informs European engineers as to the special conditions and difficulties met with in North America. Mr. Watson.

There can be no doubt but that, in this matter, Europe is far ahead of the United States. The reasons for this appear to be chiefly political, and are certainly not due to any lack of enterprise or ability among American engineers.

In the old countries of Europe, especially in England, Germany, and Switzerland, the municipality has reached a wonderful development, and gives promise of increased progress in the future.

The comparisons given by Mr. Hering between town refuse in the United States and town refuse in Europe are exceedingly valuable, and the writer has examined them carefully in order to ascertain, if possible, whether the difference in the material was sufficient to account for the lack of progress in the cremation of refuse in the United States. The conclusion drawn from Mr. Hering's valuable analysis is that the difference in the actual material is not sufficient to account for it. The chief difference, it appears, lies primarily in the methods of collection.

* "Die Städtische Verbrennungsanstalt für Abfallstoffe am Bullerdeich in Hamburg." Ed. 2, Braunschweig, 1901.

† Stadtrat; Generalsekretär des internationalen Comites für Strassenhygiene.

‡ Kaiserlicher Regierungsrat.

§ Manager and Director, Horsfall Destructor Company.

Mr. Watson. Further, the writer would point out that no refuse destructor of a true English type appears to have been tried in the United States up to the present time. Nearly all the designs hitherto adopted embody arrangements for firing with coal, coke, petroleum, or natural gas, and the refinements which have been introduced in English practice for measuring the air supply, for heating it before admitting it to the ash-pit, and for reducing to the lowest possible minimum the admission of cold air over the grates, are absent in most of the designs hitherto adopted in the United States.

In South America, on the other hand, there are several successful destructor installations of true English types dealing with refuse, which certainly cannot be superior to that found, for instance, in New York or Boston.

It would be extremely interesting if some American municipality would undertake the erection of an up-to-date destructor upon any of the well-known English systems so as to settle, once for all, whether there is any necessity for additional fuel.

In Europe, generally speaking, all the house refuse is collected together, ashes and garbage being mixed in the receptacles, as well as in the collecting carts.

In Great Britain, where coal is lavishly burned in open grates, this is a great advantage to the material from a burning point of view, because of the large quantity of cinders contained.

In Berlin, on the other hand, where brown coal briquettes are burnt to a fine ash, the collection of the ash with the garbage is a great disadvantage to the burning, as it is fine and incombustible and chokes the fires.

It may be remarked in passing that street sweepings and slop from street gullies are nearly always dealt with separately, the horse droppings, of which they chiefly consist, being valuable as manure, while the sand can be washed and used, if its market price warrants such an operation.

In the United States, it would seem that the chief difficulty about burning the household waste is that the garbage is collected separately from the cinders, and is, therefore, brought to the works in a very moist condition, containing no less than 70% moisture, according to Mr. Hering, while there are no cinders to act as an absorbent. In Berlin, the writer understands that the fine ashes from the stoves are now being collected separately, and he has no doubt that when another attempt is made to deal with the garbage by burning, much better results will be obtained.

To judge from Table 4, the writer would think that if the house refuse of New York, Boston, or Washington were collected all together without the street sweepings, it would not only be auto-combustible, but capable of raising steam to a valuable extent. In

regard to Table 7, Mr. Hering remarks that much of the ash-bin refuse in England is screened before burning. This is not quite correct, as practically the only screening operations in Great Britain are at Glasgow, Manchester, and Lett's Wharf (City of Westminster), where, in each case, the fine stuff is sent away for manure, and only the rough material that does not pass through the screen is burnt. Mr. Watson.

Another remark made by Mr. Hering upon which the writer would like to offer a further observation is to the effect that automatic arrangements were originally introduced for labour saving, but have not survived owing to the varying nature of the material. In regard to automatic clinkering, this is perfectly true, but it is not correct if applied to automatic charging. Large sums were spent by the Manchester Corporation in connection with the late Mr. Whiley's patent for mechanical grates for destructors, but unfortunately they were a complete failure for the following reasons:

They depended for their action upon traversing the material forward in the furnace, and delivering it at the front in the form of hard burnt clinker. It was found, however, that with such a low grade of fuel as town refuse, the fire would not run back through a thin layer of it, as fast as the grate-bars passed it forward, and, consequently, after an hour's working, the fire was all pushed out of the furnace, and nothing remained but cold refuse. No schemes or alterations which could be tried were found to overcome this fundamental difficulty, and, in the writer's opinion, the difficulty is unsurmountable, and if automatic clinkering is ever successful, it will have to be on entirely different lines, and will not have to depend upon passing the material forward in a thin layer on the grate-bars.

With regard to automatic charging, on the other hand, very great progress has been made in Great Britain. The destructors with which the writer has had experience, where this has been adopted, are at Westminster (Shot Tower Wharf), Blackpool, and Bromley. In all these cases, the charging opening of the destructor cells is sufficiently large to admit the contents of a four-wheeled van at one operation. A large lid is opened, the van is tipped, and the lid is again closed within the space of about three-fourths of a minute, as much as two tons sometimes being put into the furnace in a single charge. The immense saving over any system of charging by means of hand labour is at once obvious.

Considerable difficulty was experienced in attaining a satisfactory result owing to the great size of the lids, and the necessity for carefully balanced and easy-working machinery to operate them, and for some special means for making them smoke-tight. Metal-to-metal joints and grooves filled with sand were both found unsatisfactory. As a matter of fact, as long as there was a possibility of

Mr. Watson. the smallest leakage, the hot gases drew up toward the feed-hole, and made the lid red hot, warping it and increasing the leak. A radical cure was, however, found by the adoption of a water-sealed joint, and now that the lid is rendered absolutely gas-tight, the furnace gases seem to pond up beneath and to act as a shield protecting the lid itself from the heat of the furnace. It is now never hot enough to cause any difficulty.

The Blackpool plant, which consists of six cells, is capable of dealing with about 100 tons in 24 hours. It will be observed that by this direct method of charging, all possibility of sorting the material before putting it into the furnace is avoided, which, in the writer's opinion, is a sanitary improvement.

At the same time, it is necessary to provide some means of storage for the refuse, to keep the furnaces going after the collection for the day has ceased. The plan adopted at Westminster, Blackpool, and Bromley is to have a sufficient number of spare vans which are left on the feeding platform ready to be charged when required.

Tables 12 and 13 given by Mr. Hering appear to afford a very strong argument in favour of the adoption of cremation in preference to the reduction systems so prevalent in the United States, as they so clearly shew, from a municipal point of view, that burning costs less than reduction. No one can deny that it is preferable from the point of view of the public health, and of the avoidance of public nuisance.

The maintenance in Great Britain of high temperatures, effectually prevents the escape of smoke or unburnt fumes from the destructor, while fine dust is caught in specially constructed dust-catchers, depending for their action upon centrifugal force, thus enabling the destructor plant to be worked with no visible emanations from the chimney shaft.

Mr. Hering. Rudolph Hering, M. Am. Soc. C. E., New York City. (By letter.) Mr. Tur's paper is interesting to us because it demonstrates for French conditions what has been found to be suitable for American conditions, namely, that one definite system of disposal of refuse cannot be used in all cities. Several different methods are used in France, and they seem to be fairly well adapted to the respective requirements. The practice indicates that each city should have a separate examination made as to its special conditions, and, from such an examination, the best way of disposing of the different kinds of refuse should be determined. In general, a separation is preferred there, as here, contrary to English practice. The kitchen garbage or refuse is separately removed at the least expense, because it can be profitably utilized. Ashes, on the other hand, are most expensive to remove, probably on account of long hauls of heavy material, as in most cities in other countries.

Mr. Hering.

The writer feels much gratified at the reception and wide discussion of his paper, particularly as it treated of a subject comparatively new in the United States, and, therefore, was in many ways necessarily tentative. The discussion has brought out many interesting facts and opinions, and it is hoped that the result will contribute toward the spread of better knowledge concerning this subject, and toward the collection of more complete data, perhaps the erection of some test plants, and the installation, in America, of works which will be a material improvement on those now existing.

The writer will refer briefly to a few of the opinions, adding what he believes will assist in a better understanding of the subject in the light of American conditions.

Mr. Hulse's account of a temporary crematory at Ithaca, N. Y., improvised after a typhoid epidemic, is quite interesting, as it shows that the waste material of Ithaca was almost self-destroying under somewhat unfavorable conditions. With a properly designed furnace and with proper attention to the burning process, this experience indicates that results can be reached confirmatory of the belief that American city refuse can be destroyed economically by cremation.

Mr. Rosewater's criticism that the writer dwells upon the small expense of destruction "but seems to ignore the 85%" of the expense which is attributable to collection and haulage hardly seems merited. The writer distinctly and prominently (page 266) mentions collection as one of the three essential and natural parts of the whole problem, each of which should be "taken up separately and studied intelligently with reference to the rest." The writer further says (page 281) that "the element of cost of transporting alone sometimes becomes sufficiently important to decide the method of final disposal." The problem of collection from the financial aspect is inseparably connected with the disposal, and may, in a given case, even turn the scale from one method of disposal to another.

Attention should further be called to Mr. Rosewater's statement when referring to the water which "gives trouble in the incinerating process." Instead of evaporating the water, he thinks "that the simpler way would be to press this 95% (of water) out of the garbage * * * and then utilize the 5% of solid matter." Unfortunately, there is much misapprehension in regard to this question of water. In the first place, it would be impossible to press out all of this 95% of water. But even if it were possible, the machinery would have to be very powerful, and the garbage also entirely freed from such non-compressible materials as tin cans, metals, bones, etc., which might interfere with the pressing of the organic matter. The most practical way of ridding the garbage of its free moisture seems to be the one adopted in Europe when mixing all the refuse, namely, allowing the dry refuse and ashes to absorb it from the garbage,

Mr. Hering. and then allowing most of it to evaporate from the large surface of the pores at no expense whatever. American experience, wherever garbage is mixed with dry refuse and some ashes, also confirms this conclusion.

Mr. R. S. Weston very truly remarks regarding the disposal of garbage by feeding that its success depends largely upon careful supervision of the details. This conclusion might be properly applied to the whole refuse question. Indeed, it is the writer's observation that the attention to details alone will explain the success in Europe and the failures in America. Until the same attention can be given to these details in our country, we cannot hope for satisfactory results.

Mr. Fuller's allusion to flies as propagating typhoid fever emphasizes the care which should be given to the garbage question. Organic waste from the kitchen is not necessarily entirely free from disease germs, although probably freer than was formerly supposed by most sanitarians. We need only think of infected milk which has been a fruitful source of typhoid fever after being thrown into the garbage pail.

Mr. Stut has given us a very interesting description of the San Francisco furnace, which was constructed according to English patterns, but which fails, as the writer personally observed, chiefly on account of improper operation. Mr. Stut fully realizes the essential conditions for a successful cremation of garbage, which is the development of a high degree of heat, and gives some interesting suggestions as to how it may be done.

Mr. Watson is thoroughly posted on the European methods of refuse destruction, and has been a prominent party in their development. His discussion, in the writer's opinion, is the most valuable received. The writer's statements concerning European practice were necessarily derived from the statements of others, and during the preparation of the paper some doubtful points could not be verified, and even surmises were necessary, with the expectation that they would be corrected and amplified in the discussion.

Messrs. Bohm and Grohn, who some years ago made, what the writer believes to be, the most thorough scientific investigations on the destruction of refuse by fire with reference to Berlin, confirm the general American conclusion that the solution of the question before us "cannot be solved according to one method for all countries." They also endorse the detailed conclusions appended to the paper.

Mr. Goodrich holds that the views set forth in the paper "cannot be but disappointing to the British sanitarian." He acknowledges that his "remarks may appear to come from an extremist," yet implies that his views are "now generally accepted in Great Britain."

Mr. Hering. Outside of Great Britain, Mr. Watson, through his works and writings, is an authority second to none as regards English refuse destruction, and the opinions stated in his discussion do not entirely coincide with those of Mr. Goodrich. Mr. Goodrich's chief reason for disappointment lies in the writer's conservatism regarding the possibilities of power production from the cremation of combined American waste. He quotes temperatures of 2 500 to 3 000°, as frequently being reached, and considers the writer's range of 1 500 to 2 000° "a mistake." The temperatures quoted by the writer were taken from English writers and official reports. In Mr. Goodrich's own books,* in which he describes the furnace in which he is interested, he says: "The temperature ranges from 1 800° to 2 000° fahr., according to the rate of combustion in the cells." To appreciate fully Mr. Goodrich's present sanguine statement, it is but fair to note that he represents commercially a special design of furnace, for which he claims certain advantages over other furnaces.

Regarding the feeding question, Mr. Goodrich is strongly opposed to this method of disposal, and asks: "Are we in Great Britain wrong, or is it that the American standard of sanitation is low?" Where feeding in New England is practiced under the advice of some of our best sanitarians (Dr. Chapin, Health Officer of Providence, R. I., being one), we can safely conclude that in those cases, at least, it is not deleterious to health nor does it effect a lowering of the standard of sanitation. On the other hand, is not kitchen refuse collected from the most available sources, and also fed to swine in England? If so, we are willing to conclude that Great Britain is not wrong, and that the American sanitary standard is not low.

Mr. Goodrich opposes the disposal of refuse by dumping into water. Such opposition would be justified, as stated in the writer's paper, except in a very few instances. Ashes and dry rubbish can be dumped properly only where there is no interference with the regimen of a river, or where shallow waterways are to be improved by filling. Garbage can be dumped only where no obstruction is produced by it in a channel, and where none of it can drift ashore. The Mississippi River below New Orleans is one of these instances. Where tides fluctuate 15 to 25 ft., as along some of the shores of England, the strong inflow would naturally make sea dumping more objectionable than where the inflow is slight.

Land tipping, *i. e.,* dumping as filling, is undoubtedly objectionable, as the writer states, where there can be a subsequent offence either from putrefaction or dust. Where the entire refuse, or even garbage alone, can be covered with soil or the coarser part of screened ashes, this method cannot be more objectionable than ordinary burial, and is, in many places, also economical.

* "The Economic Disposal of Towns' Refuse," p. 280.

Mr. Hering

Mr. Goodrich's tirade against the sorting of waste relates deservedly to the English custom of picking valuable material from the combined or mixed refuse; but he should not apply it to the sorting customary in the United States. It is a very different matter to pick over a filthy mixture of partly decomposed garbage, rubbish and ashes, or merely a dry rubbish, as is done in New York, Boston and a few other cities, and as the rag pickers of Europe have done for centuries. When the house occupant sorts the refuse into garbage, ashes and dry rubbish, which is very common in America, there is no nuisance caused by throwing the garbage into one receptacle, the ashes into another and the dry rubbish into a third, particularly as the three materials are brought at different times from different parts of the house.

Mr. Goodrich further disagrees with the writer's view that an expert fireman is essential to success. The writer quoted the Hamburg experience, where success was not complete until experienced English firemen had been imported, and applied the results of his own observations when visiting well managed European furnaces and poorly managed American furnaces. A comparison would at once indicate to everyone how essential "a good fireman" is. Firemen with strong prejudices should, of course, be avoided on novel furnaces, but Mr. Goodrich admits that "with experience" on the latter "a good fireman" is "likely to develop."

The writer is charged with giving an inaccurate description of the Meldrum destructor (the furnace in which Mr. Goodrich is especially interested). Mr. Goodrich says:

"Mr. Hering's description of the Meldrum destructor is inaccurate in so far as the reference to the escaping gases is concerned. There are no baffle pillars of any kind, the hot gases in leaving the cell merely pass over a bridge into the combustion chamber which is always arranged between the destructor cell and the steam boiler."

The writer's description of the Meldrum furnace was taken from the standard English work, "The Removal and Disposal of Town Refuse," by William H. Maxwell, Assistant Engineer and Surveyor, Leyton Urban District Council. Mr. Maxwell (page 117 of his book) says:

"After passing the firebridge it will be seen* there are five rows of baffle pillars aranged to divide and break up the current of hot gases; the pillars remain constantly at a bright red or white heat, and take the place, it is claimed, of the cremator furnace commonly used in the older destructor installations."

The two English authorities should, therefore, settle the inaccuracy between themselves.

Mr. Goodrich further charges a wrong presentation of the Bea-

* From the illustration (Fig. 17), in Mr. Maxwell's book, which is a plan of the "Meldrum" destructor.

man and Deas type by saying: "There is not, nor has there ever been, a self-feeding open hopper in connection with this destructor." The expression "self-feeding hopper" was used by the writer to distinguish it from the hand-feeding, advocated by Mr. Goodrich for the Meldrum furnace. Mr. Hering.

A further exception is taken to the writer's statement that there are furnaces with natural draft, with forced draft and with steam-jets. Mr. Goodrich maintains that natural draft "is obsolete, and need not be taken into account." In America, natural draft is almost the only draft used, and should, therefore, be mentioned and criticised as the writer has endeavored to do. Mr. Goodrich makes a distinction between steam-jets and steam-jet blowers, the former being of little or no use, but the latter being used "in connection with over 70% of the destructor installations in Great Britain." That the writer referred to the latter alone is clearly shown by a sentence following the classification of drafts, stating that "steam is forced under the grate in the Horsfall furnace, and air in most of the other English furnaces." (The writer might better have used the term "steam blast" instead of "steam-jet," and "fan blast" instead of "forced draft.") But even that statement did not suit Mr. Goodrich, who further asserts that "the difference between the various types of destructors being that some use the steam-jet blower to deliver the requisite air supply, while others use centrifugal fans." Mr. Goodrich must then certainly be in ignorance of the purpose of the steam-jet blast as suggested by Mr. Horsfall. Mr. Maxwell, in the above-mentioned work, on page 99, when describing a Horsfall furnace, which he calls a "high temperature destructor," says:

"The *steam jet,* which plays an important part in the Horsfall furnace, forces air into the closed ashpit by means of surface friction at a pressure equal to ½ in. of water. This steam, in passing through the glowing carbonaceous cinders, is said to have a 'water gas' effect; it 'becomes broken up and yields two highly combustible gases; *viz.*, hydrogen and carbonic oxide, and such being afterwards burned in the atmosphere of the cells and in the service and main flues, most materially assist in raising the temperature and in consuming the noxious-smelling gases evolved from the fresh or non-charred town refuse, and aiding in these being changed into innocuous and non-smelling gases.' 'It is not *claimed* that there is any actual direct gain of heat from the formation and subsequent decomposition of the water gas, but that the action has the effect of carrying the combustion onwards to a further point in the furnace than it would otherwise reach, thus consuming smoke and other combustibles, which would otherwise escape.'"

It may be added that while the steam blast proves advantageous when the temperatures remain high, the reverse is true when the fires are low, and when the vapor introduced by the steam is pre-

Mr. Hering. cipitated against the walls and upon the refuse. The introduction of this moisture, then, injures rather than improves the combustion.

Mr. Goodrich is greatly exercised over the cautious conclusion of the writer at the end of his paper, that present English practice, by utilizing the heat only promises to reduce the cost of refuse destruction, Mr. Goodrich maintaining that it is actually being done. Referring to American conditions, where in not a single instance such heat is or has been utilized for power production, notwithstanding that several attempts were made (chiefly in Montreal and San Francisco), a cautious statement was deemed to be more useful in effecting progress than one which. in view of the extended experience in this country, might have seemed extravagant to the average American city father.

Mr. Baker, who made a careful inspection of English furnaces in 1904, says, in a paper on refuse destruction, presented to the League of American Municipalities in October, 1904:

"Perhaps the most interesting questions for us to consider are whether we also could burn our refuse without the use of supplementary fuel and whether it would be feasible to develop power from our refuse. It may be that if the various classes of our municipal refuse were mixed it would not differ materially from the mixed refuse taken to British refuse destructors. Unfortunately the available figures on this point are scanty. Personally, I doubt whether our mixed refuse has so high an average calorific value as British refuse. I think it probable that the volume of ashes in our Northern cities in winter and of the green stuff North and South in the late summer would be a harder test by far than is put on the average refuse destructor in England.

"As to utilizing heat from our furnaces the relative cheapness of fuel here makes it less of an object to do so than is the case abroad, and many of our American cities would have no use for the heat after it was developed. This would sound strange in Great Britain, where such large proportion of cities pump their sewage and operate either electric lights or railways, if not both. But few American cities, fortunately, have to pump sewage; relatively few, compared with Great Britain, own electric light plants; and practically none own electric railways. Moreover, public opinion is much divided regarding the advisability, under present political conditions, of establishing municipal electric lighting plants. A small amount of power might be advantageously used here for works purposes, but in this particular, also, we should have less occasion for power than is the case abroad, since our mixed refuse would produce less clinker to be utilized, and since good natural materials for mortar and concrete are, in most sections, relatively plentiful here."

This independent conclusion confirms the conclusion of the writer, and indicates that European practice cannot be transplanted to America unconditionally, but rather that it must be introduced with an intelligent exercise of pruning and grafting. Mr. Baker's

discussion of the present paper emphasizes this point, and also another one, *viz.*, that hereafter the entire question of refuse disposal should be considered as an engineering one, which as yet has been seldom done in the United States. Mr. Hering.

P. Tur, Esq., Paris, France.* (By letter.)†—The writer quite agrees with Mr. Hering, and maintains that the solution of this question cannot always and everywhere be the same. It depends essentially upon the general development of agriculture and industry. It must, then, necessarily vary in any country and obviously vary still more from one country to another. The two main considerations are public health, on the one hand, and, on the other, as always, the cost. Mr. Tur.

It is easily seen that if we try to comply with sanitary requirements and, at the same time, keep within reasonable limits of cost, we will arrive at different conclusions according to the localities and the times.

For all questions pertaining to the study of the disposal of town refuse, Mr. Hering's very able paper will, in the future, be a compendium of useful data and information to be consulted, even in countries where, as is the case in France, the agricultural utilization of town refuse is not likely to be stopped very soon.

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†Translated from the French by Paul A. Seurot, M. Am. Soc. C. E.

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TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

THE MANUFACTURE OF STEEL.

Congress Paper No. 68.

STEEL PRODUCTION IN THE UNITED STATES.

By William Metcalf, Past-President, Am. Soc. C. E., Pittsburg, Pa., U. S. A.

Congress Paper No. 69.

NOTES ON THE METALLOGRAPHY OF STEEL.

By Bradley Stoughton, M. Am. Inst. M. E., Department of Metallurgy, Columbia University, New York City, U. S. A.

Discussion of the Subject by

R. A. Hadfield, Sheffield, England.
Albert Sauveur, Boston, Mass., U. S. A.
Henry M. Howe, New York City, U. S. A.
Oswald Erlinghagen, Remscheid, Germany.
William R. Webster, Philadelphia, Pa., U. S. A.
J. P. Snow, Boston, Mass., U. S. A.
William Metcalf, Pittsburg, Pa., U. S. A.
Bradley Stoughton, New York City, U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

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Paper No 68.

THE MANUFACTURE OF STEEL.

STEEL PRODUCTION IN THE UNITED STATES.

By William Metcalf, Past-President, Am. Soc. C. E.

This article is a comparison of the production of steel in the United States in the years 1892 and 1902, showing advances in the decade in capacity, quantity and quality.

It was the intention, originally, to take the years 1893 and 1903, but the year 1893 was one of phenomenal depression and 1903 one of remarkable activity, so that a comparison of them would hardly give a fair average of progress; besides, the statistics for 1903 are not compiled completely and are not available at the time of writing.

The statistics given are the work of Mr. James M. Swank, General Manager of the American Iron and Steel Association, whose distinction and world-wide reputation are a sufficient guaranty of accuracy and completeness.

Capacity.

The sizes of Bessemer converters and Open-Hearth furnaces, in gross tons, were as follows:

In 1892 there were converters of 3, 5, 7, 10, 15 and 20 tons in use.

In 1892 there were in use Open-Hearth Furnaces of from 5 to 35 tons.

In 1901 there was no increase in size of converters.

In 1901 there were many Open Hearths of 50 tons and one of 75 tons.

The sizes in use in 1902 are not published, but it is fair to assume that there was little change from 1901.

TABLE 1.—Total Annual Capacity.

	1892.	1901.
Bessemer	6 560 000 net tons.	12 938 000 gross tons.
Bessemer-Clapp-Griffith	170 000 " "	.....
Open-Hearth	1 550 000 " "	8 289 750 gross tons.
Crucible	105 000 " "	175 000 " "
Totals	8 385 000 net tons.	21 402 750 gross tons.
Or	7 486 607 gross tons.	

It will be observed that, while the output of Bessemer steel was about doubled, the increase of Open-Hearth was more than eight-fold, and Crucible steel increased only one-third; the quantity of miscellaneous being comparatively insignificant.

TABLE 2.—The Production of All Kinds of Steel Ingots and Castings, in Gross Tons.

	1892.	1902.	Increase in 10 years.
Bessemer	4 168 435	9 138 363	4 969 928
Open-Hearth	669 889	5 687 729	5 017 840
Crucible	84 709	112 772	28 063
Miscellaneous	4 548	8 386	3 838
Totals	4 927 581	14 947 250	10 019 669

The estimated world's production of steel is given as 10 948 000 in 1889, and 30 680 000 tons in 1901. Judging by these figures,

Table 2 indicates that the United States is keeping up with the world's progress.

Having given the figures of quantity, showing a large increase, the question naturally arises, what of quality?

In the finest grades of Crucible tool steel, there has been no improvement in quality in the last forty years. Manufacturers forty years ago were making steel that has never been improved, but prices were excessively high, so that the uses were limited; ordinary grades were selling as high as from 14 to 16 cents per pound.

The introduction and development of the manufacture of tool steel in the United States aroused the attention of iron manufacturers to the possible field that was opening, and they followed it up, with the result that now the same quality of steel is sold at 6 cents per pound, or even lower, and the quality, if anything, has been improved; leaving only the very finest grades not improved upon, and not reduced much in price. These remarks apply strictly to Carbon steels. There has been a marked development in the production and use of alloy steels, which will be discussed later.

In Bessemer steel, and in Open-Hearth steel especially, there have been marked improvements. The enormous development of Open-Hearth steel has undoubtedly limited the application of Bessemer steel to fewer purposes than would otherwise have been the case, but there can be little doubt that this competition has kept Bessemer steel makers up near to the highest attainable limit of uniformity and quality.

In Open-Hearth practice, there has been a great improvement in handling large heats, so as to produce much more uniform steel than the practice of ten years ago permitted. This is more marked in the higher steels, which are the most difficult to make.

The low steels most commonly in use, not higher than from 0.20 to 0.30 carbon, were made always with satisfactory uniformity, but the demand for higher carbons led to a great deal of trouble. To illustrate: In order to overcome serious objections to car springs, specifications were made fixing an allowable maximum of P., S., Mn. and Si., and limiting Carbon between 0.90 and 1.10.

The use of this steel led to an immediate and marked improvement in the quality of springs, so great that the specifications were

adhered to and have become standard. The P., S., Mn. and Si. apparently gave no trouble, but the Carbon limits were so hard to attain in 30 to 50-ton furnaces that some of the ablest and most successful steel makers, after repeated trials, said frankly that they could not do it, and the making of this material was relegated to small furnaces of from 5 to 10 tons capacity. To-day, the same steel is made in 50-ton furnaces with satisfactory regularity; that is to say, if the mean of a heat is 1.00 Carbon, it will rarely run as low as 0.90 or as high as 1.10 in any part of the heat, and this result proves to be entirely satisfactory in practice.

Table 3 gives a list of variations which manufacturers are willing to guarantee.

TABLE 3.

Carbon desired.	Limit guaranteed.	Carbon desired.	Limit guaranteed.
0.10	0.08 to 0.12	0.60	0.52½ to 0.67½
0.20	0.15 " 0.25	0.70	0.62½ " 0.77½
0.30	0.25 " 0.35	0.80	0.70 " 0.90
0.40	0.35 " 0.45	0.90	0.80 " 1.00
0.50	0.42½ " 0.57½	1.00	0.90 " 1.10

This degree of uniformity has proved to be entirely satisfactory in practice, and this is one of the chief reasons for the great increase in the output of Open-Hearth steel, and the very small increase in the quantity of Crucible steel.

For many purposes, where Crucible steel was used formerly, and sparingly on account of cost, Open-Hearth steel is used now with entire satisfaction, and in great quantities because of its comparative cheapness and excellent quality.

Up to this time no Open-Hearth steel has been made which will take the place of Crucible steel for fine lathe work, complicated tools such as milling cutters, etc., heavy, high-speed cutting and the finer engraved dies; but while it seems to be hardly possible to reduce the cost of Crucible steel to where it can compete with

Open-Hearth steel, it is always possible that the quality of Open-Hearth steel may be improved so as to meet the best that the crucible can produce, and the next generation may learn to look on the Crucible process as one of the abandoned arts.

Heat Treatment.

Much has been made of late of the matter of heat treatment of steel, due chiefly to the persistent statements of metallographers of the marked effects on structure of comparatively minute differences in temperature and treatment, and, owing to the vital importance of the subject, it is well that some person has at last aroused the attention of engineers. As a matter of fact, it is no new thing. Experienced steel makers have understood it all along, and from time to time they have called attention to it, apparently to little purpose.

Any man who is fit to manage a mill knows very well the importance of proper heat treatment and is pretty sure to use it in his own interest, if not always in the interest of his customer.

One illustration may be interesting: A large heat of spring steel is made to specification; it contains:

Carbon	between 0.90 and 1.10
Phosphorus	<0.05
Sulphur	<0.05
Manganese	<0.50
Silicon	<0.20

It conforms to the specification, and is furnished in sound, beautifully-rolled bars, and is accepted. In the hands of the spring makers it is so red-short that it breaks in pieces and cannot be used.

Clearly, the red-shortness was not due to Sulphur or any other recognized impurity; equally clearly, the mill men understood heat treatment thoroughly and the spring makers did not.

In the making of steel, aside from the use of proper material, the one vital, all-important matter is the melting. Steel is made or marred in the melting furnace; given the best material in the

world, if it is not melted properly, it will not make the best steel, and it is just here where skill and care pay well and cost nothing; for, given the good material, it costs no more to bring it out the best steel, than it does to blunder over it and bring it out poor stuff.

The skilled heat manipulators may make it look well, but no amount of after skill will make a lot of badly melted steel as good as it should be or as it would have been if melted properly.

These remarks apply to the Crucible as well as to the Open-Hearth steel.

In regard to science as applied to steel making, there appears to have been little improvement in chemistry except as it may apply to celerity and accuracy in the laboratory; it does not seem that any advance has been made in determining the quantities of oxygen, hydrogen and nitrogen in steel, or their effects. It is certain that they are present, and, especially as concerns oxygen, harmful; this is evident in the red-short heat to which reference has been made.

Metallographers have made many and minute investigations of the structure of steel by the microscope and pyrometer; they have shown the remarkable sensitiveness of steel to heat variations, confirming all the statements of mill metallographers and manufacturers, which have been published from time to time for many years; proving once more that when correct and accurate observations are made, the operations on the large scale and the investigations in the laboratory will agree. This far their work is valuable and to be commended. That it will lead to any extended use of the microscope and pyrometer in the mills is doubtful, for the following reasons:

There may be a variation of several hundred degrees in temperature in any furnace. In what part of the furnace shall a pyrometer be applied to determine the temperature?

There may be a difference of 1 000° in the temperature of different parts of the same bar. At what part of such a bar shall a pyrometer be applied?

Again, a furnace may be of fairly even temperature of the desired amount, with a flame that is simply cutting away the steel instead of heating it. How can a pyrometer give any indication of such a state of affairs?

In all these cases a properly skilled heater, or manager either, can determine these matters at a glance, and with absolute certainty.

A piece of steel may have been heated very badly, either too hot, too cold, or, worse still, very unevenly; the microscope will give the structure of various spots of the size of a pin head, involving much labor and time in the operations. A skilled, experienced steel worker can see the whole condition by a glance at a fresh fracture.

Nature has supplied the best pyrometer and microscope combined, in the trained eye, governed by good sense and sound judgment, and it is doubtful if, for good work, these natural faculties will ever be improved upon by any instruments of man's devising.

Alloy Steels.

Alloy steels may be defined as steels containing metals other than iron, which produce marked effects. Air-hardening or self-hardening steel, Nickel steel, and Hadfield's Manganese steel are well known, and we have no record of any special changes or advances in the decade, except that new uses are being found for them, and may lead to considerable development.

High-speed steel is the one remarkable, revolutionary development of the decade. In the necessary heat treatment, it reverses nearly all the best practice for Carbon steel; and in its work it has practically revolutionized the machine business of the world. As far as it is developed at present, it consists usually of medium Carbon, generally under 0.80, very little Manganese, from 10 to 20% of Tungsten or Molybdenum, and, generally, from 3 to 4% of Chromium, although some brands do not contain Chromium. It is hardened by heating almost to fusion and quenching in an air-blast or in cold oil.

It will make heavy cuts at a remarkably high speed for metal working, hence its name, causing a temperature that will blue steel chips and that would ruin instantly any Carbon steel tool.

To predict what may be the final outcome might lead to the idea that one had let his imagination run wild; certainly the results are already startling. So many brands are upon trial, and so many diverse claims are made, so much has been written and will be

written on the subject, and there is still so much that is doubtful and uncertain, that it seems as if this were not the time nor the place for any further discussion. That had better be left to those who are directly interested and who will doubtless make themselves heard.

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Paper No. 69.

THE MANUFACTURE OF STEEL.

NOTES ON THE METALLOGRAPHY OF STEEL.

By Bradley Stoughton,* M. Am. Inst. M. E.

Steel is not a simple, homogeneous union of iron with varying proportions of carbon, silicon, manganese, etc. Not only is it built up of individual crystals, but these crystals are of several varieties, differing from each other in chemical composition, in size, shape and mode of occurrence; and the formation of the elements into these phases follows fixed and regular laws. Moreover, the physical characteristics of steel seem to depend on those of the crystalline units and on their relations to each other. From this point of view, the constitution of steel is analogous to that of the crystalline rocks, *e. g.*, granite. An engineer having to make use of this material would not base a selection of variety on analyses of oxygen, silicon, sodium, aluminium, etc., but rather on crystalline composition; the proportions of quartz, feldspar, mica; the size and interrelations of these minerals; perhaps even their individual varieties —monoclinic or triclinic feldspar, etc.

While much of the constitution of granite is visible to the eye,

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the constitution of steel is microscopic, and often requires high magnification to make it clear. Its influence, nevertheless, is as great in one case as in the other.

In any system composed of two grains there are three forces: 1 and 2, the tensile strength of the grains; 3, their force of adhesion. The strength of the system would be the weakest of these forces, which, in the majority of cases, would be the adhesive force. In a more complicated system, consisting of several entangled grains, the strength of the system would be greater than the adhesive force of the grains. To predict this strength it would be necessary to know, besides the strength of the grains and their force of adhesion, their size and mutual relations; whence the area of adhesion and extent of entanglement would be obtained. In such a state of knowledge, which would represent the acme of the art of metallography, the strength of the system and the manner and even the path of rupture could be prophesied with certainty.

Part I.—Notes on the History of the Development of the Metallography of Steel.

At the time of the International Engineering Congress, in 1893, the science of metallography was in a somewhat fragmentary and unclassified condition. It had not yet found its place among the other sciences, nor its very important relations to them. Starting from three separate, and, apparently, altogether independent sources,[1, 2, 3, 4 and 5*] it had grown slowly at first and then with greater vigor for the few years preceding the date mentioned. In England, especially, it passed almost unnoticed by steel manufacturers until a paper by Sorby, in 1886,[6] and another, at the request of the Iron and Steel Institute, in 1887,[7] aroused much attention.

Besides those referred to, the principal workers were: In France, F. Osmond; in Germany, H. Wedding and H. Behrens; and, in America, F. L. Garrison, A. Sauveur and H. M. Howe. Up to the end of 1893, some sixty-nine memoirs had been published on the subject, including a large number of photomicrographs.

The state of knowledge at this time is well summed up in three papers presented to the International Engineering Congress[8, 9, 10]

* The numbers refer to those in the Appendix at the end of this paper.

at Chicago, and the discussion of them by several able metallurgists.

The researches of Sorby on slowly-cooled samples had shown that low- and medium- carbon steel is composed of crystals of pure iron* and a "pearly constituent;" high-carbon steel was composed of the "pearly constituent" and a carbide of iron, which had been isolated by several investigators and demonstrated to have the formula Fe_3C, or a multiple, $Fe_{3n}C_n$. Between these two classes the steel, having, as now known, about 0.90 to 1.00% of carbon, consisted entirely of the pearly constituent. By the use of very high powers Sorby had found the pearly constituent to consist of very fine laminæ of the two other constituents, intimately associated and having the appearance of disturbed strata.[6] The reason for this arrangement, and its bearing upon the history of the steel, was not at that time known, nor until about the year 1896.

Finally, Howe,[11] to simplify the distinguishing of these constituents, and to bring them into line with similar mineralogical entities, had called the pure iron "ferrite," the Fe_3C "cementite" (because of its prominence in cemented steels), and the pearly constituent "pearlyte"; names so suitable that they are now adopted universally.

Much was known also of the effect of thermal treatment on the microscopic structure. The influence of size of grain, produced by overheating, on the physical characteristics of the steel had been studied with the aid of the microscope, and in connection with the carbon content of the material. It was known that the microscope in skilful hands would tell of the previous "heat history" of the steel, detect the effect of incorrect heat treatment, discover microscopic defects and flaws, including "burnt" steel, porosity, etc., and rapidly-cooled (*i. e.*, hardened) steel could be distinguished from the same material in the soft condition.

Of the structure of hardened steel, little was known, except that it often contained the Fe_3C constituent, and an apparently homogeneous, amorphous substance, seemingly without a true structure of its own, and whose occurrence was coincident with hardness due to rapid cooling. Both Sorby and Osmond had investigated this substance and concluded that it was not a true constituent. It was not until some time afterward that Osmond proved its crystalline

*Or, more particularly, iron free from carbon.

nature, established it as a definite constituent, and named it "martensite," in honor of the German metallographist.

But microscopic examination is not the whole of metallography, and the microscope is seldom, if ever, sufficient unto itself, but more often a useful aid to other branches of investigation. Besides chemical analysis, the factors which have assisted the microscope most in the development of knowledge of the constitution of steel are: temperature measurements, and the application of laws of physical-chemistry, referring especially to solutions.

In 1893 the bearing on the microscopic structure of steel of the allotropic modifications of iron, discovered by Osmond,[12] was not appreciated. True, Osmond attributed the hardening of steel to these modifications, but the claim was not admitted by all, and many even doubted that allotropy was the cause of the thermal changes in heating and cooling at certain critical points.

When an alloy of iron and carbon cools to a temperature of about 690° cent., it spontaneously liberates heat so rapidly as to cause a reversal of the cooling; the mass rises again in temperature and brightens to an extent visible to the eye. This phenomenon of "recalescence" was first described by Gore,[14] and investigated by Barrett[15] and others. It was rightly believed to mark a change in the relation between the iron and carbon, though some claimed that it was the result of a change in the carbon itself. Above this critical temperature the carbon was said to be in the condition of "hardening" carbon; below it, in the condition of "cement" carbon. In the hardening condition it was known to be dissolved in the solid iron; in the cement condition it was combined with a proportionate amount of iron as Fe_3C—"cementite." If the high-carbon steel was quenched in some cold menstrum while the carbon was dissolved, the cold material would be glass hard; if the same steel was allowed to cool slowly until the "recalescence" had ended (and a little longer) it would be in a relatively soft condition.

Osmond, by examining the thermal changes in low-carbon steels at temperatures higher than "Gore's phenomenon," found that there was not one, but three, critical points. He believed that those occurring at temperatures above 690° were due to molecular changes in the iron itself, that is allotropic modifications. Whether the two new points each marked an allotropic change, or whether they

were merely different stages of a single change, he did not care to state, in the then incomplete condition of the knowledge of the subject, though he was inclined toward the first hypothesis.[16] He did not define in print a distinction between the two points until 1892.[17]

In a memoir communicated to the International Congress at Chicago, Howe[18] published his investigations on the two new thermal points discovered by Osmond, and an able review of this part of the subject.

Osmond had found that the critical points were encountered on heating the steels, as well as on cooling, but they occurred at higher temperatures in the first case. He believed them to be, nevertheless, simply opposite thermal effects of the same changes in the steel. Howe's contribution showed this to be so.

Osmond believed that iron existed in a very hard allotropic form above the temperature of his newly-discovered points, and in a soft form below those temperatures; that the hardening of steel by rapid cooling was due to the circumstance that the lack of time under such conditions prevented the iron from changing into the soft variety. The carbon, he thought, hindered the change, by acting as a sort of brake, and this explained to him the well-known fact that the extent to which steel can be hardened increases with increasing carbon content.

Increased Impetus in the Study of Metallography.

The time had now come, as Howe declared, to turn from mere microscopic examination to experimental investigation of the relations of the various observed facts to each other, and their bearing on the physical characteristics of steel.

Two very powerful influences began now to stimulate research along these very lines: The first was interest awakened in the subject in practical men in all branches of engineering, which resulted in the appointment, and the hearty support, of committees of experts to investigate the problems encountered; the second was the warm controversy which arose between the advocates of the allotropic and the non-allotropic theory by which the hardening of steel was explained.

In 1890 the Alloys Research Committee of the Institution of Mechanical Engineers asked Professor (afterward *Sir* William) Roberts-Austen to carry on the work for which the Committee had been formed and financially aided by the Institution. Under his skilful leadership this Committee has presented to the Institution five reports, dated 1891, 1893, 1895, 1897, and 1899, dealing partly or wholly with alloys of iron. It will be seen that its work has had a potent influence in advancing our knowledge of the constitution of iron and steel.

In 1893 the *Société d'Encouragement pour l'Industrie Nationale* created a prize of 2 000 francs, to be awarded to the author of the most valuable investigation on alloys, and, in 1896, appointed a *Commission des Alliages* to carry on investigations in this subject and to secure the assistance of other scientists. In this work the Society was well supported financially by industrial works, railroads and individuals, which shows how great and how general was the interest in the subject. Some of the contributions resulting from this enterprise have exerted a profound effect on our knowledge of the metallography of steel.[19]

In 1894,[20] 1895[22] and 1896[26] a vigorous discussion went on between those who believed that the thermal retardations first observed by Osmond were caused by allotropic changes in iron, and those who attributed them to some other change. The ranks of the latter class became gradually smaller, and finally very small indeed, the disagreement diminishing to a difference of opinion on the definition of allotropy. Meanwhile, another discussion grew out of the first controversy: Many metallurgists were led by the evidence to believe that pure iron undergoes critical molecular changes (allotropic modifications), but could not concede that the hardening of steel was to be ascribed to these, or, in any event, to these alone. They believed, rather, that rapid cooling from the temperature where the carbon is dissolved in the iron rushed that solution through the temperature range in which it could decompose and so preserved it, by denying it the time to break up, down to the temperatures where the mass became so cold that its rigidity prevented the possibility of any changes. Thus they perpetuated it, and the hardness of the steel they believed to be due to the hardness of this solution. They argued: since the carbide itself is hard, the hardness of even slowly-

cooled steel is greater the greater the amount of carbon there is present, but the separated carbide does not cause the same hardness throughout the whole mass of the steel as if the carbon had remained uniformly dissolved. The advocates of this "carbon theory" declared that the "allotropic theory" required experimental evidence that there existed a hard modification of iron, which evidence was not forthcoming. The "allotropists" retorted that the small amount of carbon present was not sufficient to cause the glass-hardness of quenched steel; that almost carbonless iron was capable of assuming a hard form, if quenched with extreme rapidity; that neither normal iron nor carbon was hard, and that a solution of the two would therefore not be hard, unless the iron was in an abnormal form; that iron was the only metal which was hardened by various impurities, which indicated that the hardening effect was due to some peculiarity of the iron, and, finally, that low-carbon steel quenched above the temperature of Gore's phenomenon was not as hard as the same steel quenched above the temperature of Osmond's critical points.

Two compromise hypotheses were suggested: The first, by Howe,[22] said that the hardness was probably due to both carbon and allotropy, and, perhaps, to the preservation by rapid cooling of a carbide of an allotropic form of iron; the second, by Sauveur,[27] suggested that the hardness was due to the preservation of a solution in iron, not of carbon, which is soft, but of the carbide, which is harder than even the hardest of hardened steels.

These several theories are still in dispute, and to them another has been added, which credits the hardness to internal stresses in the quenched steel. So able a physicist as André Le Chatelier[28] holds this hypothesis. He calls attention to the change of volume which takes place in iron while suffering the allotropic modification through which it recovers its magnetic susceptibility. He states that this dilation tends to occur in quenched steel at a time when it cannot be relieved by an increase in volume, because it is held both by the cooled exterior shell and by an unyielding net-work of carbide. The influence of carbon is both to increase the intensity of the stresses and to lower the temperature of allotropic transformation. Field[29] also suggests a hypothesis to account for the hardening by internal stresses.

The difficulties of learning the exact condition of steel at high temperatures have baffled all attempts to solve them. Since the solutions cannot be studied direct they have had to be investigated as closely as possible in relation to the results of their effect in changing back and forth—that is, of critical points in cooling and heating curves, etc.—and steels of varying carbon-content, quenched at different temperatures, have had to be examined under the microscope. This has not been a fruitful source of knowledge of the nature of hardening, but it has increased greatly our information on the constitution of steel, and, in this way, perhaps contributed as much of practical value as if the question of the scientific cause of hardening had been settled instead.

The Work of Gibbs and Guthrie.

Before outlining the present state of knowledge of the constitution of steel, it is necessary to consider certain theorems which have led to this point:

In 1874–75, two communications were made to the scientific world which were destined to exert great influence on metallurgical thought. The first, by Professor J. Willard Gibbs[30] of Yale, initiated a revolution of chemical theories which has caused Gibbs to be classed by many with the illustrous Lavoisier; the second is no less important to metallurgists, because of its influence in revising our theories of solutions, under which head it is now known that all alloys, including iron and steel, belong at some period of their manufacture, and to whose laws they are subject. A knowledge of the theory of Guthrie[31] is necessary to an understanding of the constitution of iron and steel, as revealed by the microscope. It explains with great clearness the reason for the presence in all steels of the pearly constituent, and the existence of separated ferrite in some and of the carbide, Fe_3C, in others.

That algebraic doctrine of Gibbs, now known under the name of the *"phase law,"* was not all of his theorem, but is the part of it which has found the greatest application to the problems presented to the student of iron and steel. It was not until about 1884 that, under the leadership of such men as van't Hoff, Bakhuis-Roozeboom, Meyerhoffer, Henri Le Chatelier and others, this doctrine had been

reduced by experiment to a guiding principle in the classification of the constituents resulting from solutions comparable with steel, and it was not until 1896 that the theory of solutions was applied to cooling steel. There is this difference between the two cases: that, solid steel at high temperatures is a solid solution of carbon and iron; while the theory of solutions has been used principally in studying liquid solutions. The analogy between the two, therefore, passed unnoticed for some years.

The application of the phase law to the metallography of steel is so important that a very brief statement of its principles is desirable here.

The Phase Law.

For any system in equilibrium the phase law expresses algebraically the relation existing between the number of chemical components, the number of phases in which these components exist, and the stability of the equilibrium of the system under variations of internal forces. The variations of internal forces are brought about by varying the temperature, or the pressure, or the forces of solubility (*i. e.,* by increasing either the degree of dilution or concentration).*

The components of a system are the chemical elements contained in it, or the compounds which act like elements—that is, which are not decomposed in any part of the range in which the system is to be studied. The phases are the homogeneous physical or chemical entities in the system. For instance, when iron is a component, *alpha, beta* or *gamma* allotropic modifications may be phases, as also, liquid and solid iron. Fe_3C may be a phase in a system in which iron and carbon are components. In aqueous solutions, H_2O is a component, water and ice are phases. And so on.

Algebraically stated, the phase law declares that:

$$L = n - r + 2$$

$$\left.\begin{matrix}\text{The stability of equilibrium}\\ \text{of the system under varia-}\\ \text{tions of internal forces.}\end{matrix}\right\} = \left\{\begin{matrix}\text{The number}\\ \text{of}\\ \text{components}\end{matrix}\right\} - \left\{\begin{matrix}\text{The num-}\\ \text{ber of}\\ \text{phases}\end{matrix}\right\} + 2.$$

A single example will make the application of this principle clearer. Consider a system composed of pure iron at atmospheric

* One should remember here that the forces of solubility are by no means negligible quantities. To appreciate this the single example of the dissociation of a compound into its ions by means of solution might be recalled, a force often equivalent to the pressure of high temperature.

pressure and a temperature of 1 000° cent. This system will have one component (iron) and one phase (solid, *gamma* iron). It will have a degree of stability of 2, which means that either the temperature or the pressure may be varied without destroying the equilibrium. Therefore, it has strong stability under variations of internal forces. Suppose now the pressure is retained as constant and the temperature is varied until 1 535° cent. is reached; the iron begins to melt. There is now the same one component,* but two phases (solid and liquid iron). The equilibrium is now less stable; neither the temperature nor the pressure can be varied without destroying equilibrium.† It has a value of $(L = 1 - 2 + 2)$ unity. At this point, then, there is a transformation of the system.

Starting again from the original system, if the temperature is decreased to 900° (the pressure remaining constant), another transition is reached. At this temperature and pressure there is the same component, but two phases (*gamma* and *beta* iron). Again there is a stability with a value of 1.

The phase law teaches the degree of stability of equilibrium under different numbers of variations; it does not teach anything of the amount by which any of the influences may be varied before equilibrium is destroyed. For example: water is in a state of stable equilibrium everywhere between its freezing and boiling point, but this does not tell us how many degrees of temperature or pounds pressure there will be between these points. In other words, the phase law interprets, but does not replace research. In the simplest cases just considered the results of research might be interpreted unaided by any algebraic theorem, but in the case of complex heterogeneous systems the circumstance is different.

The application of the phase law may be seen more clearly by reference to the graphical representations in Figs. 1 to 3, which apply to the study of solutions. Here, the writer has indicated the degree of stability of equilibrium of a system by the equilibrium of a cube acted upon by forces in three horizontal directions, and resting upon a plane. When resting on one of its sides it is in stable equilibrium (Fig. 1). A force might tend to tip it, but, if not acting too long, would not bring it into another transition form

* The number of components of a system never varies.

† Unless, of course, both were varied together in such a way that their influences would counteract each other, which would be the same as varying neither.

—*i. e.*, upon another side. This condition corresponds to a value of $L = 3$ or more, by the phase law applied to a solution. Suppose, now, that a force has acted so long as to tip the cube so that it is balanced upon one of its edges (Fig. 2). It is now in equilibrium, but unstable. The forces cannot be varied in either direction, *A* or *B*, without destroying equilibrium, unless both are varied by a corresponding amount, but the third force can be varied somewhat, without such destruction. This balanced state corresponds to a value of $L = 2$. Its condition corresponds to a transition point of a solution along a line,* as may be represented by the circumstance that the cube itself is in a transition state along a line. Finally, let it be supposed that the cube has been brought to a position of balance upon one of its corners (Fig. 3). It is still in equilibrium, but of the most unstable variety, which corresponds to a value of

REPRESENTATIONS OF DEGREES OF EQUILIBRIUM OF SOLUTIONS WITH TWO COMPONENTS.

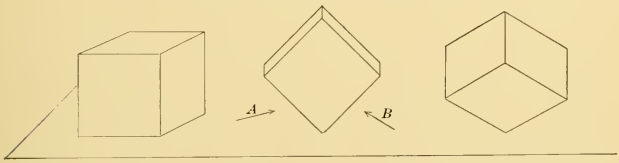

FIG. 1 FIG. 2 FIG. 3

$L = 1$, for solutions, and to the intersection of two or more transition lines—that is, to a transition point (*e. g.*, the point *S* in Figs. 4 and 5).

There are four questions with which the phase law is concerned.

1.—Is the system in a state of equilibrium?

2.—If so, what is the degree of stability of this state?

3.—How many components has the system?

4.—How many phases has it?

When any three are known, the phase law will determine the fourth. While it is impossible to restrict the statements closely, it may be said that the microscope has been most useful in answering Questions 3 and 4, and the measurement of heat changes,

*For example, any point along the lines *G–S* and *E–S* in Figs. 4 and 5, except their point of intersection.

Questions 1 and 2. The phase law has classified the data thus obtained.

The Theory of Solutions.

To understand the theory of solutions, attention is called to Fig. 4, which represents graphically the changes that occur in the cooling of solutions, with varying degrees of concentration, of NaCl in water. The ordinates are temperatures; the abscissas are percentages of NaCl, and also of water. The line, *E–S*, is the locus of the limits of solubility of NaCl at the different temperatures.

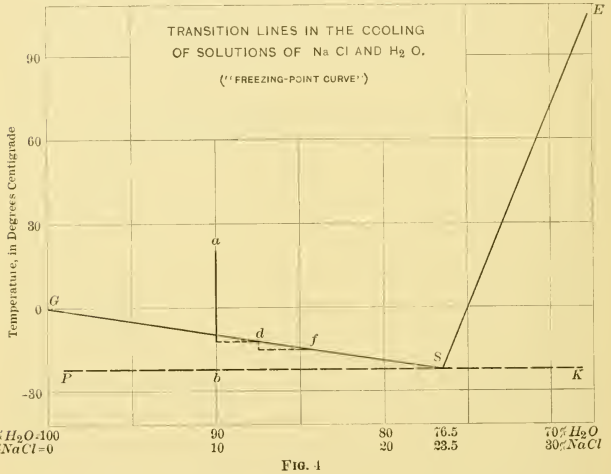

FIG. 4

In other words, the abscissa of any point on this line represents the largest portion of NaCl that can be retained in solution at the temperature of the corresponding ordinate. Similarly, the line, *G–S*, is the locus of the limits of solubility of water at the different temperatures. We must recognize that the forces of solution are mutual between the NaCl and the water; that the water is held in solution by the NaCl, as well as the converse.

Consider now a solution cooling from 20° cent., and containing

10% of NaCl and 90% of water (the point, *a*, on the diagram). No change will take place in this system until it reaches a temperature of approximately —10 degrees. The curve shows that it cannot go below this point and retain all the water in solution. Suppose it cools to —12 degrees. At this temperature the curve shows that no more than (approximately) 87% of water can be retained in solution. Therefore the difference, 3%, will be precipitated. The solution will now travel to the point, *d*, on the curve. The system has now changed; instead of there being only a solution, there is a new solution, represented by a new point on the diagram, plus 3% of deposited water. Water normally solidifies at zero; therefore, as soon as the water found itself released from the forces of solution it solidified. Suppose the system now to consist of a saline solution and some ice. Consider now only the solution at the point, *d*. Suppose it cools to —15°, it must precipitate enough water to bring it to the point *f*, whose abscissa is the maximum proportion of water that will be retained in solution at that temperature. Thus the system will continue decreasing in that part which is in solution and increasing in precipitated ice, until, at a temperature of —22°, there will be a solution with 76.5% of water and 23.5% of NaCl, mixed with ice whose amount will be equal to the difference between the original abscissa of the system and that of the point, *S*.

Since any system which cools down to the line, *G–S*, will commence precipitating ice at that line, the line, *G–S*, is the locus of true, or first, freezing points of all these solutions. Also the path of cooling of any solution to the left of the point, *S*, will be a vertical line until the line, *G–S*, is reached, after which the solution will travel along the line, *G–S*, and progressively precipitate out corresponding proportions of water. On being deposited, the water will at once solidify.

By similar reasoning it can be shown that any system to the right of the point, *S*, will, on cooling, travel vertically until it reaches the line, *E–S*, and then divide into two parts: 1, a solution which travels along the line, *E–S*; and, 2, precipitated NaCl, increasing in amount with each fall in temperature, and solidifying immediately on being released from solution. All such systems, on reaching a temperature of —22°, will consist of a solution

containing 23.5% of NaCl, and 76.5% of water (the maximum amounts which can be retained in solution at that temperature), mixed with some solid NaCl.

Therefore, any solution of NaCl and water, whatever its original composition, will, on cooling to —22°, consist of a solution of 76.5% and 23.5%, respectively, of water and NaCl, mixed with either ice or solid NaCl, or neither (if the system started with exactly those proportions).

The temperature of —22° is the lowest at which even the most soluble proportions of water and NaCl will remain in solution in each other. Therefore, if cooled further, this most soluble mixture will decompose, and practically all the water and NaCl will separate.* Both will immediately solidify, being already far below their normal freezing points, and will form in tiny parallel flakes of NaCl and ice, intimately associated and having a structure somewhat like Fig. 1, Plate XI. The point, *S*, therefore, is the lower or final solidifying point of all the solutions of NaCl and water.†

Guthrie believed that, because all the aqueous solutions of NaCl showed this segregation to a definite composition, and also the solutions of many other salts, these definite mixtures were hydrates, and he gave to them the name of "cryohydrates." [31] Later, however, on realizing that they were not compounds, and that their formation was physical, not chemical, he discarded this theory.[32] For metallic solutions formed like the aqueous solution at the point, *S*, Fig. 4, Guthrie proposed the name of "eutectic mixtures." On account of similar claims to-day, in regard to the mixture formed by a like process in steel, it is interesting to note Guthrie's abandonment of his original hypothesis.

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*In this argument the writer has, for simplicity, purposely ignored the fact that the ice and salt which separate will each contain very small proportions of the other.

†Many writers describe the line, *P–K*, as the locus of the lower solidifying points of all solutions of NaCl and water, but the writer prefers to follow the example of certain physicists and call the point, *S*, the lower solidifying point. The difference is merely one of expression; there is no disagreement about the action which occurs. The writer has been, and has known others to be, perplexed by the line, *P–K*, drawn in full.

It is true that a system starting on any abscissa will show a critical point at the place where the abscissa cuts the line, *G–S*, or *E–S*, as the case may be, and another critical point at -22°, which might look as if the line, *P–K*, was a critical point for all systems, but the transition point at -22° is not a transition point for the system; it is only a transition point for that part of the system remaining in the condition of a solution, and that part is concentrated at the point, *S*. For example, consider the system which starts at the point *a*; When this system reaches the temperature of -22° it can still be represented as a whole by the point *b*, but the system, as a whole, certainly undergoes no transition; it is only a part of it that suffers a change. But metallurgists are accustomed to study these curves with the line beneath the V, so the writer has represented this accordingly, but has drawn the underline dashed to indicate that it is not a transition line.

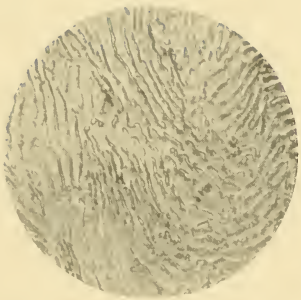

FIG. 1.—EUTECTOID STRUCTURE.
Steel of 0.90% Carbon, Very Slowly Cooled.
Etched with 5% Picric Acid.
Magnified about 1 000 Diameters.

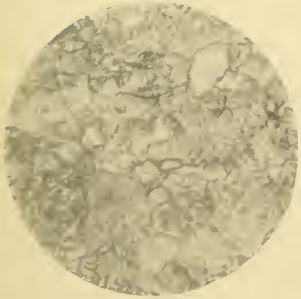

FIG. 2.—FERRITE.
Electrolytic Iron.
Etched with 5% Picric Acid.
Magnified about 1 000 Diameters.

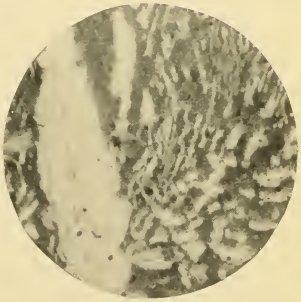

FIG. 3.—Fe_3C + EUTECTOID.
Cemented Bar.
Polished in Relief.
Magnified about 250 Diameters.

A Dynamic View of Solutions.

To understand more clearly the reasons for these phenomena of solutions, let them be considered from the standpoint of imaginary forces. Water normally solidifies at 0° cent., and this action represents a not inconsiderable amount of energy, as indicated by the heat liberated. NaCl solidifies at 772 to 775° cent., this action being also an energetic one. Since water and NaCl are practically insoluble in each other when solid, there are conflicting forces in all the solutions of the two at all temperatures below the solidifying point of NaCl: First, there is the force of the tendency of the NaCl to solidify; opposed to this is the force of solubility tending to hold the NaCl in solution. The greater the proportion of water to NaCl, the greater will be the force which holds the NaCl in the solution, and *vice versa.* The line, *E–S,* represents the locus of equilibrium between these conflicting forces. The further the temperature is below the solidifying point of NaCl, the greater will be the force tending to cause its solidification, therefore the greater must be the relative proportion of water in the solution to supply an equal force of solubility; therefore NaCl will precipitate out progressively on cooling to maintain this equilibrium of forces. Similarly, the line, *G–S,* is the locus of points of equilibrium between the force of solidification of water and the opposed force holding the water in solution. Finally, in a solution at the point, *S,* there are four forces in equilibrium: (1) the force holding NaCl in solution, (2) the force holding water in solution, (3) the force tending to cause solidification of NaCl, and, (4) the force tending to cause solidification of water. The sum of (1) and (2) opposes the sum of (3) and (4). By no usual means can the sum of forces (1) and (2) be increased; because any increase in (1) [for instance, by increasing the relative proportion of water in the solution] would cause a decrease in (2), and *vice versa.* Therefore, the least fall of temperature below the point, *S,* causing an increase in both (3) and (4) at once, destroys the equilibrium; the forces of solubility give way, and precipitation and solidification result.*

Where the two substances are soluble in each other even after

* In using the metaphor of forces to elucidate the principles of solutions, the writer does not desire to be misunderstood. The metaphor is a metaphor only; it seems to make the facts clearer, but the writer does not wish to imply that these particular forces have been studied independently in this class of solutions. Probably the system of forces actually existing would be more complex than has been represented here.

solidification, the forces of solubility are not opposed to the forces of solidification in the same way. The locus of average solidification points of such systems is approximately a straight line from one solidification point to the other.

The Role of the Le Chatelier Thermo-Electric Pyrometer.

A new and greater era in metallurgy began with the introduction of Le Chatelier's thermo-electric pyrometer. Its influence has been far-reaching, and one of the first sciences to come within its sphere was the study of the behavior of metals at high temperatures, and especially of steel. The writer has stated that, in the application of the phase law to steel, temperature measurements have been most potent in answering the questions of changes in states of equilibrium. The measurement of other physical variants, such as dilation, magnetic susceptibility, etc., and observations on changes of state—solidification, etc.—have aided, but not to as great an extent.

Referring again to Fig. 4: If any salt solution be cooled from above the lines, *G–S* or *E–S*, and its changes noted by a thermometer, the temperature will be seen to fall according to a uniform law down to that point at which the abscissa of the solution cuts either of the lines, *G–S* or *E–S*. Here there will be an arrest in the cooling, due to the heat liberated by the congelation of the water or the NaCl, as the case may be, and this retardation of the rate of fall of temperature will continue down to —22° cent., at which there will be another, and greater, liberation of heat by the solidification of both the water and the NaCl simultaneously deposited from the solution now remaining. This latter heat liberation is often great enough to cause a reheating—"recalescence"—of the mass, causing a rise in the temperature similar to the phenomenon accompanying a surfusion.*

It is these thermal changes which indicate changes in equilibrium in the systems. Obviously, the changes may be observed

*Pure water, pure metals, and other substances are subject to the anomalous action of surfusion,—*i. e.*, remaining molten below their normal freezing points. The moment a surfused pure substance is agitated, however, it solidifies, and the temperature immediately tends to rise, and usually does rise, to the normal solidification temperature.

The case of a eutectic mixture is an example of enforced surfusion, so to speak, of the individual components. It seems to be natural that these components, immediately on finding themselves free from the forces which have hindered their solidification, should tend to rise to their normal temperature of solidification, and should thus liberate heat so fast as to cause a recalescence, even in the presence of the rapid radiation.

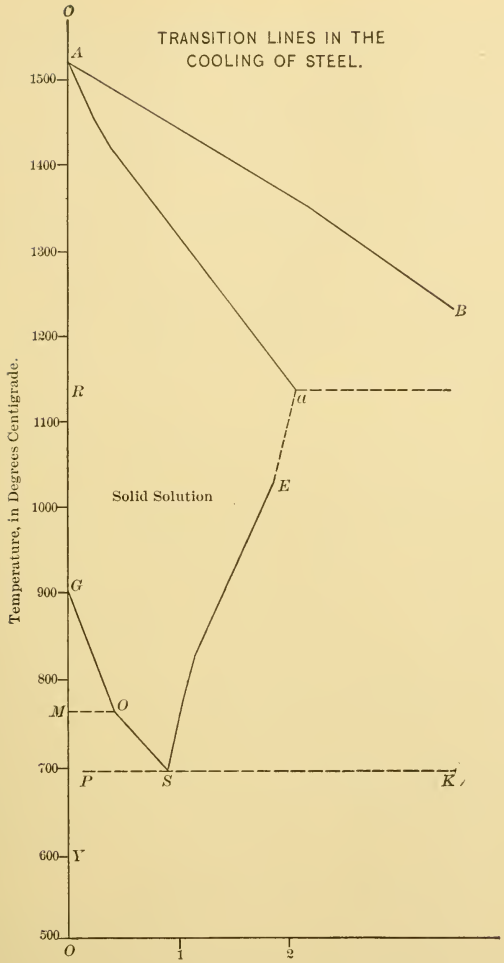
TRANSITION LINES IN THE
COOLING OF STEEL.
O
A
1500
1400
1300
B
1200
R
1100
a
Solid Solution
E
1000
G
900
800
M
O
700
P
S
K
Y
600
500
O
1
2
Temperature, in Degrees Centigrade.
Percentage of Carbon

FIG. 5.

in aqueous solutions with an ordinary mercury thermometer; not so, however, with changes occurring from 600 to 1 600° cent.

Up to 1886 no reliable instrument existed for that purpose. In that year appeared the first notice of the thermo-electric pyrometer,[33] followed, in 1887,[34] by more complete data.

Metallurgists were not slow to size the opportunity thus offered; almost immediately, Osmond began his classical researches on iron and steel, at his private laboratory in Paris, which resulted in his discovery of the allotropic modifications of iron. In 1891, Roberts-Austen[35] added to the pyrometer a device by which a cooling body would autographically record its rate of fall of temperature. It was with such a piece of apparatus that Roberts-Austen and his assistants made the investigations on the alloys of iron and carbon which finally resulted in the first systematic arrangement of them in diagrammatic form, showing the application of the laws of solutions.

Lastly, in 1898,[36] Roberts-Austen devised his extremely delicate differential method, whereby a cooling body of steel records not only the actual temperatures, but also, in connection with them, the difference in cooling between the steel and a mass of some substance which suffers no retardations. Thus is obtained a record of each variation in cooling, indicating a liberation of heat in the steel.

The Application of the Phase Law to the Constitution of Steel.

In 1895, Stansfield,[38] then assistant to Roberts-Austen, called attention to the analogy between the behavior of salt solutions and some of the alloys of iron and carbon. It was not until 1896, however, that this analogy was entirely exposed, by the researches of Roberts-Austen, assisted by Stansfield,[39] on cooling curves of a complete series of alloys of iron and carbon. Almost at the same time as this publication, H. Le Chatelier[40] independently observed and mentioned the similarity in the formation of "pearlyte" to the formation of the eutectic mixtures of solutions.

In Fig. 5 these facts are shown graphically.[41]

Consider now pure molten iron: This system occupies the line, *O-O*. On cooling to the temperature of 1 535° cent. it solidifies probably as the *gamma* allotropic modification. On cooling to the

point, *R* (1 130°), it undergoes a transition, whose nature is not understood at present. On further cooling to the point, *G* (900°), the iron undergoes another change, as indicated by a retardation in the rate of cooling, and at least two physical changes in the metal. This change is believed to be the change from the *gamma* to the *beta* allotropic modification. On cooling to the point, *M* (762°), another arrest in the cooling curve is observed, which is believed to mark the change from the *beta* to the *alpha* allotropic modification. At this point the iron meets with a marked change in the magnetic characteristic. Finally, at about 600°, there is another critical point in the cooling curve, whose significance is yet unknown. Roberts-Austen[42] suggests that it may be due to a molecular change (*i. e.,* allotropic change), and he says that Morris[43] had found a change in magnetic permeability at this temperature.

Within the area, *G–O–S–E–a–A,* all the alloys are solid solutions of iron with varying amounts of carbon from zero to 2 per cent.

Considering now changes in the alloys: The line, *G–O–S,* is the locus of the limits of solubility of iron in a solid solution of carbon and iron. In this respect it corresponds with the line, *G–S,* in Fig. 4. The line, *E–S,* is the locus of the limit of solubility of carbon in the solid solution of carbon and iron. When the carbon separates out progressively along this line, it immediately unites with iron to form the compound, Fe_3C. The effect of these two actions is, therefore, as if Fe_3C itself separated out along this line.* The line, *E–S,* is comparable with the line, *E–S,* in Fig. 4.

The point, *S,* is also comparable with the point, *S,* in Fig. 4, for every alloy of iron and carbon (up to 2% of carbon) will allow to separate either iron or Fe_3C progressively until the solution remaining at the temperature of 690° cent., will have the proportions of the abscissa of the point, *S.* On cooling below this temperature, the solid solution at the point, *S,* will itself decompose, separating iron and Fe_3C, exactly as the eutectic mixture broke up in the salt solution considered previously. Thus is learnt the meaning of what the microscope had already taught: that all low- and medium-carbon steels consist of crystals of iron ("ferrite") in a

*Some metallurgists do, in fact, maintain this theory, and believe that the solid solution is not of iron and carbon, but of iron and Fe_3C. There is no definite information on this point. Certain actions to the right of this figure—that is, iron with more than 2% of carbon—would indicate, however, that Fe_3C is so unstable at high temperatures that it must be dissociated in this solution.

ground-mass of the pearly constituent, while all high-carbon steels consist of crystals of Fe_3C in a ground-mass of the pearly constituent. The pearly constituent was known to consist of laminæ of ferrite and Fe_3C; it is now recognized as corresponding to the decomposed eutectic mixture of liquid solutions. Many refer to it as the eutectic of steel, but this name seems hardly justifiable, for eutectic implies lowest melting point, which is true for the segregated mixtures in liquid solutions, but not in solid solutions. Therefore, Howe[4] has suggested for this mixture in steel the name "eutectoid," which seems to be faultless.

The eutectoid structure is found in all slowly-cooled steels. Evidence, however, shows that it is not a primary component or constituent of steels, but is itself complex. It is a mechanical mixture, formed by physical agencies, and has none of the attributes of a true chemical component, and none of the forces of chemical union. Its mechanical characteristics, however, are important: It is formed of extremely small crystals or plates of ferrite and Fe_3C, requiring high powers of the microscope to distinguish the structure, and this minuteness of grain-size may be the reason why the maximum tensile strength of steel is found at about 1% of carbon, for steel of this composition consists entirely of the eutectoid structure. Other considerations might lead to the thought that steels of higher carbon would be stronger, because such steels contain a larger proportion of the very strong constituent, Fe_3C, but the Fe_3C crystallizes in large plates, and it is known that the larger the crystallization the less the strength of the steel and the greater the brittleness, in general.

The point, *S*, is not confined absolutely to one abscissa; pyrometric data, and examination with a microscope both seem to manifest that all slowly-cooled steels with proportions of carbon between 0.90% and 1.00% consist entirely of the eutectoid. This is probably due to the lack of delicacy of the instruments, as the very small amount of ferrite or Fe_3C that would separate from solution between these abscissas would be difficult to distinguish under the microscope from the same constituent in the structure of the eutectoid, and would cause only a slight perturbation in the cooling curves. The cooling curves of Carpenter and Keeling, plotted in Fig. 5, which were taken with the thermo-electric pyrometer, by the very

delicate differential method of Roberts-Austen, seem to show a critical point for the precipitation of ferrite from the alloy containing 0.81% of carbon, which is indeed precise work.

The line, *A–B,* is the locus of the "true freezing points" of the alloys of iron with up to 2% of carbon—that is, of pure iron and all steels. The line, *A–a,* is the locus of the lower freezing points. Between these two lines the various alloys are in a pasty condition —part solid and part liquid. The line, *A–a,* predicted by Roozeboom,[45] from analogy with other solutions, is now known experimentally to be present.

It may be inferred that the *gamma* modification of iron is isomorphous with carbon, and that the *beta* and *alpha* modifications are not, for the initial precipitation of iron from the solid solution seems to coincide, as nearly as the instruments will indicate, with the change from the *gamma* modification, exactly as, in the salt solution considered, the initial separation of water coincided with its normal freezing temperature. In other words, using again the metaphor of forces, it is the force of iron tending to cause it to change to the *beta* or the *alpha* form, a force always increasing with every fall in temperature below the point of change in pure iron, which resists the forces holding the iron in solid solution, and causes a progressive deposition of iron along the line, *G–O–S.* As soon as iron is released from solution it, of course, undergoes the allotropic change. In agreement with this reasoning it would be expected that all alloys which separate any ferrite above the temperature of 762° (*i. e.,* alloys with less than 0.38% carbon), would encounter a retardation in the cooling curve at the point where the ferrite separates (*i. e.,* the point where its abscissa cuts the line, *G–O*), and another retardation at 762°, which latter is due to the second allotropic change now taking place in the released ferrite. This action is known actually to take place.

What is the force dragging carbon out of the solid solution against the forces of solubility? It would seem to be the affinity of carbon for iron, tending to cause the reaction: $_3Fe + C = Fe_3C$. Above a certain temperature, Fe_3C seems to be an unstable compound; in this range there will be offered no resistance to the retention of carbon in solution. But, at all temperatures below that at which Fe_3C is stable, there will be a constantly increasing

resistance. The line, *E–S,* represents the equilibrium between the force of this resistance and the solubility of carbon.*

Le Chatelier[40]† found a critical thermal point in highly-carburetted steels at a temperature near 800°, which he believed to be due to a molecular change in the iron in the solid solution—probably the change which takes place at 900° in pure iron. Such a change he likens to the change which occurs in the water of aqueous solutions, which still shows a maximum density, but at a temperature displaced from the normal point. In their recent researches on steel, Carpenter and Keeling[41] find this critical point in all steels with 0.80% and more of carbon.

Carpenter and Keeling also find a critical point in almost all the steels they investigated, at a temperature near 600°, confirming the investigations of Roberts-Austen on electro-iron. This, of course, is to be expected, for every system below 690° consists of uncombined Fe_3C and ferrite, and this uncombined ferrite in steel would undergo any modification which pure iron would suffer.

These last two points, however, seem not to be connected with any changes in microstructure.

Tschernoff denoted the point at which all steels suffer a retardation on heating or cooling by the letter, A. This is the temperature of Gore's phenomena and of the point, *S,* in Fig. 5. After finding additional retardations, Osmond retained the nomenclature of Tschernoff, but called the temperature of the point, *S,* A_1; that of the point, *M,* A_2, and that of the point, *G,* A_3. Furthermore, Osmond differentiated between the points of retardation on heating and on cooling,[12]‡ It has already been declared that the critical points on heating occur at a temperature above the corresponding point on cooling. To the points met with on heating, Osmond gave the names: Ac_1, Ac_2, Ac_3; and the corresponding points on cooling he designated as: A_{r1}, A_{r2}, A_{r3}. It is usually the A_r points which are plotted on diagrams similar to Fig. 5. Finally, Osmond used these letters to indicate, not only the critical thermal points, but also the critical change which occurred in the substance at those points. Consequently, A_{r3} is used to designate the changes which

* In the present condition of knowledge of the factors influencing these various changes all theories must be advanced with the reservation that subsequent investigation may expose a better one Especially is this true in regard to all speculations on the reversible reaction: $3\,Fe + C = Fe_3C$.

† See p. 63 of No. 40.

‡ See pp. 12 and 13 of No. 12.

occur all along the line, *G–O*; and $A_{r3\text{-}2}$ (or sometimes, A_{r2}), changes all along the line, *O–S*. The designation A_{r3} is also used for the changes occurring along the line, *E–S*—the separation of Fe_3C—though, logically, this use is somewhat irregular.

It is very interesting to note that the evidence of changes in stability of equilibrium of alloys of iron and steel by critical thermal points, has been confirmed by critical points of other physical characteristics, and the transition lines of Fig. 5 roughly duplicated. Thus, critical changes in magnetic properties have been observed by Hopkinson,[46] M.[47] and Mme. Curie[48] and others; in electrical resistance by Osmond, Le Chatelier, Boudouard and others;[49] and in dilation by Le Chatelier,[50] and especially by Charpy and Grenet.[51] In regard to the latter property, it is to be noted that dilation and temperature changes are related more closely than temperature and the two former physical characteristics. The changes in dilation might be merely a result of the changes in temperature.

Part II.—The Relation Between the Microstructure of Steel and Its Physical Characteristics.

Steel is primarily a series of alloys of iron and carbon. The proportion of manganese and silicon may be, and sometimes is, several times that of the carbon present, and the proportion of phosphorus as great, but it is the percentage of carbon which usually gives to steel its grade, and determines its principal characteristics. It has been seen, however, that it is important, nay, necessary, to consider more than the mere amount of carbon present; its mode of occurrence may modify essentially its influence by weight alone. All slowly-cooled steels are made up of grains or crystals of ferrite and Fe_3C. The steels used mostly in construction are composed very largely of ferrite. The more one can learn, therefore, of the physical characteristics of this constituent, and of Fe_3C, the better will one understand how to make and how to use steel.

Pure Iron-"Ferrite."

Theoretical ferrite is pure iron, and, more particularly, iron free from carbon. It is not certain that such a pure substance exists, but the name is usually applied to the nearly pure metallic

constituent found associated with the carbide of iron in all slowly-cooled steels, and found associated with carbide of iron and graphite in all slowly-cooled cast iron. The industrial product approaching nearest to ferrite is the purest form of wrought iron. Ferrite has the highest electric conductivity and magnetic susceptibility and permeability of all the constituents of the iron and steel series; it is the softest, most ductile and weakest, having a tensile strength of about 45 000 lb. per sq. in. It is white in color, and crystallises in the isometric system.

Under the microscope, ferrite may be distinguished from the carbide of iron by its softness. If steel containing these two constituents be polished on damp, rouged parchment or chamois-skin, stretched over a soft background (as wood), the ferrite will wear away below the carbide and appear in intaglio. The same effect will be obtained by Osmond's "polish attack."[52]

Ferrite is also distinguished from carbide of iron by the fact that after subjecting to the brief action of certain reagents, such as 2% nitric acid, or ordinary commercial tincture of iodine, the ferrite is seen in grains and the carbide in thin plates, not attacked by the reagent. When the two are intimately associated in minute grains, the carbide appears bright and the ferrite dark because eaten away below the surface by the reagent.

Ferrite crystallizes always in the cubic system, and Osmond[53] and Stead[55] have studied the variations of the forms assumed by it and by its alloys with carbon. Osmond, especially, has studied the crystallography of the *gamma, beta* and *alpha* modifications of the pure metal. He finds that *gamma* iron assumes all the combinations of the cube and octahedron, and, in the latter form, would be isomorphous with carbon in the diamond form. In the isomorphous mixture (*i. e.,* solid solution) of iron and carbon one would expect therefore to find some carbon in the diamond form—which has actually been accomplished by Moissan, as is well-known. This is another strong argument for the belief that the solid solution of iron is with carbon, not with Fe_3C, for Osmond has shown[54] that Fe_3C does not assume any crystalline form which would be isomorphous with ferrite.

Gamma iron does not crystallise isomorphously with either *beta* or *alpha* iron, a fact which accords with the observed tendency of

iron to separate from the solid solution at all temperatures where it is not normally in the *gamma* allotropic form. *Beta* and *alpha* iron crystallise identically, in cubes, with many modifications on the edges, and none on the angles.

It is only with extreme difficulty that nearly pure iron can be obtained, and then it absorbs carbon voraciously if heated in contact with it or almost any of its compounds, solid, liquid or gaseous. The best known means of securing ferrite for investigating purposes is to deposit it electrically from the purest possible anode and electrolyte.[55a]

Fig. 6 shows a cooling curve of electro-iron, recorded by Roberts-Austen, using his differential method. It will be seen that there are six critical points. Roberts-Austen thinks[36] the points, *X* and *W*,

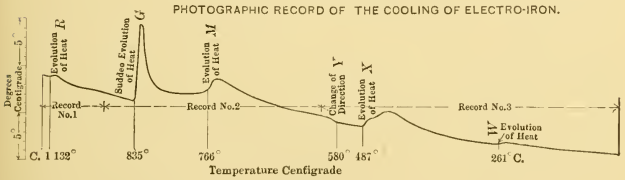

FIG. 6.

have to do with the presence of hydrogen in the iron. He found that repeated heating of the iron *in vacuo* to 1 300° cent., caused them to disappear. It also had the effect of reducing the intensity of the thermal changes at Ar_3, Ar_2 and Ar_1.

The points, *G* and *M*, are the points, Ar_3 and Ar_2 respectively. The point, *R*, is a critical point first observed by Ball.[56] It is coincident with a critical change in magnetism. The significance of the point, *Y*, has been discussed in reference to Fig. 5. Roberts-Austen suggests that it be designated Ar_0, and it would seem logical to extend the nomenclature to the point, *R*, also, and call it Ar_4.

The evidence in favor of believing that iron undergoes allotropic modifications at the points, Ar_3 and Ar_2, is now very strong. Both points correspond to a change in direction of the curve of electrical resistance of the material, which rises constantly with

increase in temperature, shows a slight, but always noticeable perturbation at Ar_2, and a decided transformation at Ar_3, above which point the resistance of the material does not sensibly increase with the temperature. Le Chatelier* found Ar_3 more noticeable with measurement of electrical phenomena than with that of heat changes. The other investigators who have been most prominent in the study of the critical points by the electrical method have also found a marked change corresponding to Ar_3 in both ferrite and low-carbon steels.[57]

The study of ferrite by magnetic methods shows decided evidence of marked critical points. Curie[47] studied the variations of magnetism of soft iron and low-carbon steel. He found a critical change at Ar_2, another at Ar_3, and a third at the point discovered by Ball. The latter is the most remarkable, for iron which had become almost non-magnetic above Ac_3 suddenly increased by one-half of its amount, and then gradually diminished again with further rise of temperature. The researches of several scientists have revealed the fact that the point, Ac_2, is that at which pure iron loses almost entirely the power of being attracted by a magnet, and Ar_2 that at which it regains that power. In other words, *beta* and *gamma* iron are almost non-susceptible to magnetic force. Steel with 0.90% or more of carbon loses its susceptibility at the moment it forms the solid solution (Ac_1) for, of course, the iron dissolves as *gamma* iron. Similarly, all steel regains some susceptibility at the moment ferrite separates, provided the separation takes place at a temperature below Ar_2.

It has already been pointed out that variations in expansion of steel with temperature duplicate roughly the critical points obtained by other observations, but the effect of temperature on dilation is such that it might be argued that the critical points in dilation were a result of the changes in temperature, and not of molecular changes.

Finally, Osmond[58] has shown, in a masterly memoir, that the point, Ar_3, is a critical point in the thermo-electric characteristics of iron.

Howe[59] and others have demonstrated that practically carbonless iron is stronger and less ductile if cooled very rapidly from

*In No. 49 will be found references to Le Chatelier's memoirs.

above Ar_3, and that low carbon steel is stronger if quenched above Ar_{3-2} than if quenched above Ar_1. In other words, the changes which take place at the upper critical points, which admittedly are independent of changes in relations of iron and carbon, themselves produce changes in the strength of the metal.[22—26]

Important evidence on this point is furnished by Galy-Actié,[60] who showed that iron containing no carbon, and but a trace of phosphorus, could be hardened either by sudden cooling or by mechanical treatment, but that this hardening, unlike that of steel containing carbon, passed away with time.

Fe_3C—"Cementite."

Cementite is carbide of iron, Fe_3C. It is the hardest, most brittle and strongest of all the constituents of hardened or unhardened iron and steel now known. It is white in color and crystallizes usually in thin, flat plates.

It contains 6.67% of carbon and has a hardness of 6 in the mineralogical scale. The ordinary reagents used in etching previous to microscopic examination color and attack cementite less than any of the common constituents.

During the past decade much has been learned of cementite. Several additional investigators have isolated it, and especially E. D. Campbell,[61] working on isolated carbide, has determined the heat of formation of one gram to be 47 calories, and that the crystallized carbide is practically unacted upon by the neutral solutions of ammonium or potassium cupric chloride, and unless there is a small amount of free hydrochloric acid present. Campbell also claims[62] to have isolated another carbide, $(Fe_2C)_n$, from an annealed, pure white iron.

The best method of isolating the carbide from its association in steel and iron is the electrolytic one of Arnold and Reid.[63]

Cementite is magnetic at ordinary temperatures, but not at temperatures above the point Ar_{3-2-1}. (690° cent.)

The carbon united with the iron in cementite has been given various names; such as, cement carbon, or carbon of cementation, because of its prominent appearance in cemented steels; annealing carbon, because all the carbon of well-annealed steels will usually

be present combined as cementite,* and carbon of the normal carbide.

Relation Between the Characteristics of Slowly-Cooled Steels and the Proportions of Ferrite and Fe_3C.

In Fig. 7 will be seen the tenacity, ductility and mineralogical hardness of iron with varying percentages of carbon—that is, the physical characteristics of these various mixtures of ferrite and

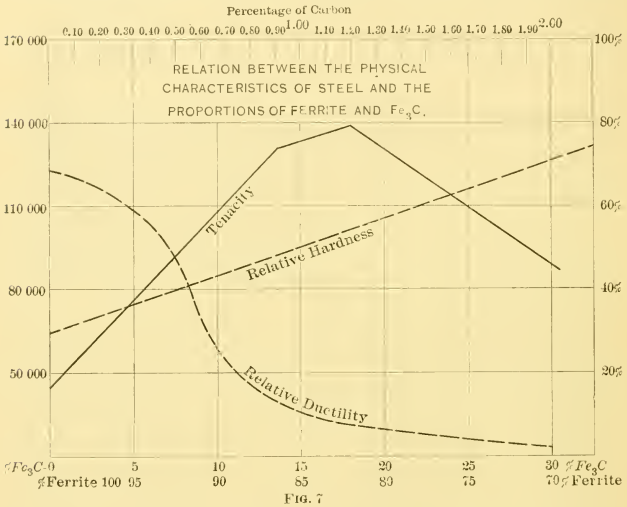

FIG. 7

Fe_3C. This diagram, taken from Howe,"† shows, as would be expected, that the softest, weakest and most ductile of the alloys is pure ferrite, and that there is, with certain exceptions, a decrease in these characteristics with each increase in the proportion of the hard, brittle and strong Fe_3C.

The largest variation from a straight line is in the case of the ductility. Ewing and Rosenhain[64] have shown what happens when iron and other metals yield to strain. The plasticity, according to

* Arnold has doubted this, *Journal*, Chemical Society, 1894, Vol. LXV, p. 788.
† See p. 162 of No. 44.

their indubitable results, is due to a finite number of slips along the cleavage planes of the individual crystals of the metal. These slips begin in all metals as soon as permanent deformation occurs and result from all kinds of strain producing such deformation. A pure metal strained beyond its ultimate strength, fractures through the said cleavage planes; an impure metal may fracture through the separating of crystals from each other, that is, through breaking down of the crystalline adhesion. But, in each case, the plastic yield which precedes fracture is due to slips in the planes of the crystals. This throws valuable light on the disproportionate decrease in ductility with decrease in ferrite. While sufficient evidence is lacking to supply a definite theory, enough has been shown to demonstrate the importance of future microscopic investigation in this direction.

In the absence of really suitable means for determining the mineralogical hardness of steels, the line representing this has been sketched in approximately. It is almost a constant variant with the amount of Fe_3C in the alloy, as would be expected.

The curve for tensile strength bends first at about 0.95% of carbon, that is, the point at which the steel consists entirely of the eutectoid structure. It reaches a maximum at a little more than 1 per cent. In the present state of knowledge one can only conjecture the reason for this behavior. It is suggested that the presence of plates of Fe_3C in all steels above about 1.10% of carbon, which plates are constantly increasing in amount and in size, would tend to destroy the continuity of the material and produce a weakness greater than would be compensated for by an increase in the proportion of the stronger constituent. A glance at Fig. 3, Plate XI, will explain the writer's meaning.

Constituents of Rapidly-Cooled Steels.

The constitution of steel which has been rapidly cooled from above the temperatures of the critical range is not capable of easy investigation. No means have yet been found of examining this material at temperatures in which it is in equilibrium. To develop the structure of steel for microscopic study it requires a very thorough polishing, followed by treatment with certain chemical reagents, which, by their different actions on the various con-

stituents, produce changes visible to the eye. The great problem has been to raise the polished steel to a temperature of, say, 900° cent., without oxidising its surface, and then to treat it with reagents and examine it through a microscope. Obviously, all liquid reagents, which have been used customarily, are unsuitable. Sauveur has proposed etching with gaseous hydrochloric acid, and Saniter[55] has exhibited great skill in etching with molten $CaCl_2$, but the results were not altogether successful.

Certain steels have critical changes below the atmospheric temperature. Examples of these are Hadfield's manganese steel, and nickel-steels with about 25% of nickel. A study of these steels would indeed reveal their structure above the critical points, but the presence of so much manganese or nickel lessens their similarity to ordinary carbon steel in the corresponding ranges.

The method adopted usually is to raise the steel to the temperature desired and then cool it as rapidly as possible. The theory of this is that the rapid cooling suppresses more or less completely changes which would take place in slow cooling, by denying the necessary time for their completion. This reasoning agrees with fact to some extent, but it has never been possible to cool so rapidly as to obtain non-magnetic steel (*gamma* iron) at atmospheric temperature, and often the rapidly cooled steel shows traces of separated ferrite or Fe_3C.

By this reasoning, steel within the area, *A–G–O–S–E–a*, should be a homogeneous solid solution of iron and carbon.

Osmond, whose work on rapidly-cooled steel stands pre-eminent, has found already three different structures in this class of material, but the true nature of none of them is known. It is not even known that they are true normal constituents, and Osmond[45] himself has expressed a belief that some are transition stages between the solid solution and ferrite plus Fe_3C.

Martensite.—The best known of these structures is martensite, which was known to Sorby, but first described accurately by Osmond and named by him in honor of Adolph Martens. It is usual to speak of martensite as if it were the solid solution normally existing within the area, *A–G–O–S–E–a*, but if it has not the characteristics of a solid solution, and Osmond has suggested[45*] that it is

* See Osmond's discussion in No. 45.

probably as much of the solid solution as could be preserved by rapid quenching. That is, it is a decomposition product of the solid solution, in which decomposition has been prevented as far as possible. In his most recent publication on this subject, he expresses a doubt whether martensite is a primary constituent, but does not attempt to say what it is.[52]

But martensite is the entity of which ordinary hardened steels mainly consist, and therefore its characteristics are contributed in due proportion to this material. Hardened steels are used for only an extremely small number of purposes, such as armor plate, burglar-proof safes, etc., but, in the discussion of these articles, the characteristics of martensite enter.

Martensite is of variable composition: it may contain anywhere from almost zero up to 2% of carbon, and its hardness is a function of the proportion of the metalloid. With low carbon, it is sometimes almost as soft as ferrite; with 1.50 to 2%, it is next to the carbide in hardness. Its tensile strength and brittleness follow a similar law. It is very crystalline in structure, and colorless or pale yellow. The best method of developing the structure is by Osmond's polish-attack, and it requires a magnification of nearly one thousand diameters to show it. Tincture of iodine colors it yellow, brown or black, according to the proportion of carbon contained. Osmond describes its appearance as follows:[52]

"There are then seen faintly engraved groups of needles, or, rather, of rectilinear fibres, arranged parallel and sometimes separated by grains of a vermicular or worm-like character. Three systems of fibres, respectively parallel to the three sides of a triangle, cross frequently in the same region, and characterise, according to the opinion which M. Michel Lévy has given me, crystallites of the cubic system."

Troostite.—Troostite is another structure which would seem to be a transition state, for it is best obtained by rapidly cooling from within the critical range itself, or by tempering. The latter operation converts, or tends to convert, martensite to troostite. Troostite therefore, is a probable constituent of many, or all, tempered steels, and as such is important to makers and users of tool steels, but the very fact of its being not a true primary constituent of steel, but an intermediate state, should make one very cautious in ascribing any

properties to it. A recent attempt to identify it is unsatisfactory: it contradicts the evidence of two of the most skilful metallographers of our time, and bases some arguments on unsupported microscopic evidence, a practice which has always been overbold. After ten years' acquaintance with it,[60] Osmond still[52] speaks of its nature with the greatest caution. Further researches on this constituent, consisting of microscopic examination confirmed by independent and related evidence, is very desirable.

Sorbite.—Sorbite is another entity for whose discovery we are indebted to Osmond. Remembering that the nature of all these structures found in rapidly-cooled steels must be spoken of with reserve, it may be stated that sorbite is the last stage in the formation of the eutectoid. It may be described as incipient eutectoid, nascent eutectoid, unsegregated eutectoid, etc. That is to say, it is the eutectoid structure in which the flakelets of ferrite and Fe_3C seem to be still incompletely separated from each other. It may be obtained by hastening the cooling, but without quenching, or by quenching and tempering nearly up to Ac_1, or by quenching at the end of the Ar_1 change.

The crystalline structure of sorbite is even finer than that of the eutectoid, and therefore, according to observations, it should be stronger and more ductile. Experience confirms this prediction, and serious attempts have already been made to improve the quality of steels by modifying their treatment so that part of their structure which should be eutectoid will consist of sorbite instead.[67]

Lest the position of sorbite be misunderstood, attention is called to Fig. 5. To produce a sorbitic structure in steels, no difference would be made in their cooling until the temperature of the ordinate of the point, *S*, is reached. At this temperature, whatever was the original composition of the steel, there is a certain amount of solid solution of 0.90% carbon, with separated ferrite, or separated Fe_3C, as the case may be. On further cooling this solid solution would decompose into separated ferrite and Fe_3C. By hastening the cooling only slightly, from this point, the progress of the change is sufficient to give the ductility of slowly-cooled steel, but to retain so much entanglement of the ferrite and Fe_3C as to increase the cohesion of the mass.

Austenite.—The last constituent to be discovered is austenite,

which Osmond suggested[68] is the solid solution of *gamma* iron and carbon, and which he named in honor of Sir William Roberts-Austen. It simplifies ideas if the true solid solution can be regarded as identical with austenite, for which there seem to be several good reasons, and the pseudo-constituents, troostite and martensite and sorbite, as transitions between austenite and ferrite plus Fe_3C, a nomenclature suggested by Osmond[68] and adopted by Howe.[69] The system in vogue at present whereby one author calls the solid solution martensite, another calls it austenite, and so on, is most confusing and discouraging to the best of men. In this paper the writer has attempted to refer to the solid solution by that name. It is only a little longer than the shortest of Osmond's memorial titles, and requires no effort of memory to make the meaning clear.*

Austenite is obtained by quenching steel of more than 1.10% carbon from a temperature of at least 1 000° cent., and in a bath of 0°, or a little lower. Even then the whole mass is not austenite. The largest amount Osmond has been able to obtain is 70%, for, in spite of the most rapid cooling possible, Fe_3C separates from the solution. Austenite is differentiated from martensite by treatment with a 10% solution of hydrochloric acid, which colors the martensite, the action being more regular if strengthened by weak electrolysis. Austenite is differentiated from the other constituents in the same way as martensite.

The fact that austenite can only be preserved to atmospheric temperatures when the "brake action" of carbon is potent, and by extremely rapid cooling, suggests that it is the true constituent normal above the lines, *G–O–S* and *E–S*, in Fig. 5. Additional reason for this belief, if it amounts to a real belief, is that it is less magnetically susceptible than martensite, and that it cannot be machined by the hardest tool steels, but it will be scratched by a needle, which martensite will not. In other words, it is extremely strong, but not extremely hard, in this respect resembling Hadfield's manganese

* By this the writer does not intend to criticise these very suitable names when necessary, which applies at all times when there is occasion to refer to a structure before its true nature is known. This applied for a long time to pearlyte, but now that once useful title can be dispensed with for the more suitable one of "eutectoid," which at once identifies the structure and tells of its true nature, without any effort of memory. Ferrite probably cannot be dispensed with, for the name iron is too broad in meaning to suit a constituent. Cementite, however, is now used not only for Fe_3C, but for $(FeMn)_3C$, for a possible Fe_2C, etc., etc.

To conclude this digression: great credit is due him who discovers a new constituent, especially if it be of benefit, and to him belongs the right to name it if he will, but great credit also be it to him who discovers the nature of the constituent and thus allows science to discard an unnecessary name.

steel after quenching, which is known to be a solid solution of carbon, iron and manganese.

The name hardenite, which Osmond still uses for martensite of the abscissas of the point, *S*, in Fig. 5, is no longer of use, and should be discarded.

Mode of Occurrence in Steel of Elements Other Than Carbon.

Manganese.—Next to carbon, manganese is the most important element present in steel. At the finish of the Bessemer and open-hearth processes it is added to de-oxidise the steel, which, without this service, would be worthless. To all steel it confers strength, and especially counteracts the bad effect of sulphur. When present in amounts of from 11 to 14%, as in the material known as "Hadfield's manganese steel," it produces a substance, the first known to man, having at once great strength and toughness.

In de-oxidising the bath, it clearly leaves the steel immediately, probably as MnO. Both FeO and Fe_2O_3 have been found in steels, but never MnO, as far as the writer is aware.

Manganese possesses so much affinity for sulphur that all the manganese will unite with that element until there is none left. Any excess will then form the compound $(FeMn)_3C$, which closely resembles Fe_3C in its physical characteristics and crystalline habit. It may be distinguished under the microscope, and isolated chemically, by the methods suggested for Fe_3C. It crystallises in thin, flat plates, often of large size. Cavities in pigs of high-manganese pig iron will frequently contain many of these hard, brittle sheets, whose surfaces show a beautiful variety of oxide colors.

The affinity of manganese and carbon for each other increases so greatly the forces of solubility in the solid solution normal above the lines, *G–O–S* and *E–S*, in Fig. 5, that the temperature of its decomposition is lowered with each increase in manganese in the steel. In Hadfield's manganese steel the temperatures of decomposition are well below that of the atmosphere, and said steel is therefore a solid solution at ordinary temperatures. It is not only very hard and strong, but is almost without the power of being attracted by a magnet.

Silicon.—Silicon seems to be present in steel in combination with iron. Carnot and Goutal have found the compounds FeSi and Fe_2Si (which Moissan has made in the electric furnace), in ferro-silicon

and ferro-manganese, respectively,[70] and E. D. Campbell finds a probable Fe_3Si in pig iron.[71]

Sulphur.—When there is sufficient manganese present, all the sulphur will be combined with this. Lacking it, the excess sulphur will be found as FeS. This action is very important, for MnS is only slightly disadvantageous to steel, while FeS is ruinous. It is known that FeS is much more soluble in iron than MnS, whence the operation sometimes resorted to, of desulphurising molten pig iron by an addition of manganiferous material, followed by skimming from its surface the "cream," rich in MnS, which rises there.

Arnold and Waterhouse[72] have investigated this subject and find that FeS forms in cells surrounding the crystals of steel, while MnS segregates from the steel at a higher temperature and collects usually in globules. The "red-short" effect of sulphur they attribute to the fusibility of FeS at a bright red heat (it seems to solidify at about 900° cent.). In cooling, the FeS meshes contract from the crystals which they surround, leaving a myriad of cracks and cavities, which destroy the cohesion and lower the specific gravity of the material. This accords with the observed bad effect of high sulphur on steel, even when cold.

The MnS is still pasty at a rolling temperature, and elongates into threads very much like the action of slag under the same circumstances. But the separation of the MnS at a point where the whole material still has much contraction to undergo, lessens the formation of cracks and cavities; in fact, the crystals of steel seem to close in upon the globules of MnS and hold them firmly.

This difference in behaviour of the sulphides may be due in part to differences in the coefficient of contraction, but it is also probably due to the difference in solubility. When the MnS separates, it, too, occupies the inter-crystalline spaces at first, but gradually changes to a globular form. The FeS separates at a lower temperature, and, therefore, within a less plastic mass.

It is to be noted that both FeS and MnS are disadvantageous at either a red or black heat, but the evidence afforded shows how important it is to have enough manganese present to unite with all the sulphur. It is probable that this is usually accomplished, but some mysterious failures might be explained by an irregularity in this respect. Carnot and Goutal[73] determine the sulphur combined

with manganese in steel by treating the material with a solution of cupric potassium chloride. This reagent will not attack FeS, but decomposes the MnS present, and forms with the sulphur an insoluble residue of cupric sulphide.

Phosphorus.—Percy isolated seven compounds having definite atomic proportions of iron and phosphorus. Of these, only one, however, is of first importance in the metallurgy of steel. This is the compound having the formula, Fe_3P.

It is important to note that a eutectic is formed by this Fe_3P and iron, discovered by Stead,[74] and having the analysis of 10.2% of phosphorus, and 89.8% of iron. Its melting-point is 980° cent., and it has a eutectic structure of the cellular type (see Fig. 1, Plate XII), and not of the foliated type like the eutectoid of the iron-carbon solid solution, or many eutectics of solutions and alloys. The melting point of the Fe_3P compound seems to be at 1 060 degrees.

By treating phosphoretic pig iron with cold nitric acid (1.20), or by cupric chloride, the Fe_3P will be left in the insoluble residue, from which it can be separated by attracting with a magnet and purifying. The eutectic structure may be manifested by etching with nitric acid, but, to distinguish this eutectic from the eutectoid of iron and carbon, it is necessary to heat-tint the polished samples. By heating until the eutectoid is blue, the Fe_3C will be red, and the Fe_3P yellow.

The effect of phosphorus on steel is somewhat irregular. One is often startled (or used to be) by "discoveries" of kinds of steel which were safe and ductile in spite of high content in phosphorus. The fact is that such cases are actually found, but high-phosphorus steel is, and probably always will be, treacherous unless one learns the causes of the variable behaviour, and how to prevent constantly the embrittling effect. Phosphorus causes steel to be brittle when cold, and especially under shock; the embrittling seems to be much more effective, the greater the amount of carbon present.

More data are needed on this question, and it is to be hoped that investigators will turn their more particular attention to this objectionable impurity in steel. Phosphorus increases greatly the coarseness of crystallization of steel, and it prevents the "refining" of the grain of low-carbon steel by heating to 900 degrees. It is probable that this alone is one cause of the embrittling effect of the metalloid, and

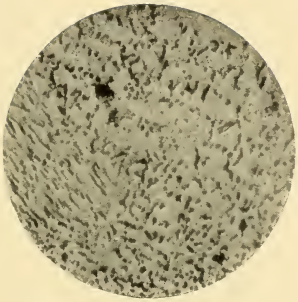

FIG. 1.—IRON-PHOSPHORUS EUTECTIC.
Etched with 5% Picric Acid.
Magnified about 1 000 Diameters.

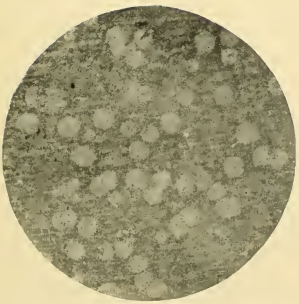

FIG. 2.—OVERHEATED 1% CARBON STEEL.
Etched with Concentrated Nitric Acid.
Magnified about 250 Diameters.

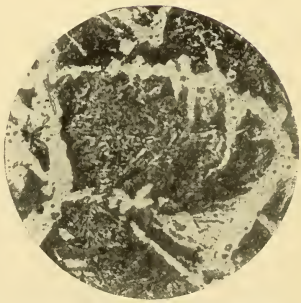

FIG. 3.—OVERHEATED 0.34% CARBON STEEL.
Si = 0.027%; Mn = 0.221%; S = 0.004%
P = 0.027%.
Etched with 2% Nitric Acid.
Magnified about 250 Diameters.

high-phosphoretic steel should never be annealed after rolling, at any temperature now known definitely, for the mechanical treatment of rolling leaves a smaller grain than can be produced by usual heat-refining. It may well be that phosphorus simply lowers the refining temperature, and that the method of treating highly-phosphoretic steels, so as to produce a minute structure, may be discovered.

The effect of carbon seems to be to throw phosphorus out of combination with the iron, as a phosphide, and this compound is likely to surround the crystals of steel and form planes of weakness which render the whole mass fragile.

Phosphorus and carbon also seem to lower the temperature at which steel may be burnt, and highly-phosphoretic steel may easily be burnt, up to the third degree of Stansfield's classification, thus suffering damage at a temperature where no such bad result should be expected. The burning, in this case, seems to be the liquating of the iron-phosphorus eutectic, taking place anywhere above its melting point. As steel is too often heated to unnecessarily high temperatures previous to rolling, the danger in the case of phosphoretic material will be appreciated.

Part III.—Microscopic Study of Faulty Steel.

On Desirable and Undesirable Crystallization of Steel.

The production of steel with correct crystalline form is of vast importance in metallurgy, and of vital interest to the user. A thoroughly good steel may be rendered unfit for use by treatment outside of certain safe limits, which are none too extensive. The danger is more grave through the circumstance that the steel may be ruined at a period of its treatment after separation from the piece which is used for a test to guide in judging of its qualities.

As long ago as 1868, Tschernoff[3] called attention to coarse crystallization engendered in steel by over-heating, and means by which the damage could be repaired. Further researches have been made by Brinell[75], and, especially, with aid from the microscope, by Stead, [76–77] and others.

The dangerous character of such badly-treated steel is due to the extreme brittleness accompanying a coarse structure. This

coarseness of grain may be observed by examination of a fresh fracture, or, with greater accuracy and reliability, by microscopic examination of polished and etched specimens.

Brittleness may be produced in low-carbon steel by two incorrect methods of heating: First, annealing at too low a temperature (say, from 500 to 750° cent.), especially for a long time, and in an oxidising atmosphere; second, by annealing for a long time at very high temperatures. Both of these processes are independent of the abuse of "burning," which causes dangerous brittleness, but from a different effect. However, among ignorant workers with steel, all over-heating goes by the name of "burning," though it will be seen that there is an important difference between the two. The range of temperature in which steel may be annealed depends on the carbon-content of the steel, but it is always within narrow limits, if good steel is to result, and within a range of not more than 20°, if the best results are to be obtained.

Even dangerously over-heated steel abused in either of the ways just indicated (if not yet burnt), may be restored to its pristine high quality by reducing the coarseness of the structure to the minutest possible size. Either of two methods suffice for this: Forging or otherwise distorting the shape of the mass from a temperature of at least 900° down to a medium red heat, will restore its crystallization to a minute size and, simultaneously, bring back its quality. The best temperature at which to finish the mechanical deformation has been determined by W. Campbell[78] to be that just below the first precipitation of ferrite from the solid solution, and as near it as possible. That is, just below the line, *G–O–S*, in Fig. 5. In other words, the exact temperature will vary with the carbon-content of the steel. In regularly treating any grade of steel, the correct temperature may be learned and adhered to for that material in all future rollings.

The second cure for brittleness of the kind now being considered, is to reheat the steel to the temperature producing the smallest grain-size. This operation will destroy the crystallization effected by the previous over-heating, and restore to the steel its desirable qualities. The temperature best suited for this remedy has been studied by Stead[77] for very low-carbon steels, and he concludes that it is, at 870° cent. A study of his valuable results, however, and

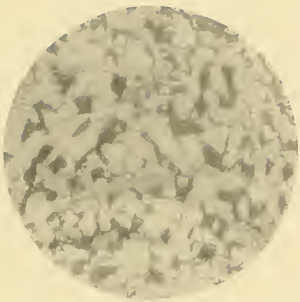

FIG. 1.—THE SAME AS FIG. 3, PLATE XII.
Refined.
Etched with 5% Picric Acid.
Magnified about 250 Diameters.

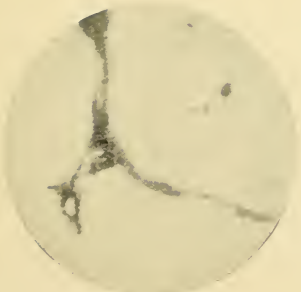

FIG. 2.—BURNT STEEL.
Unetched.
Magnified about 250 Diameters.

FIG. 3.—BLOW-HOLE IN STEEL.
Unetched.
Magnified about 250 Diameters.

comparison with those of Göransson[79] and Campbell,[78] would tend to indicate that the best temperature to which all steel should be heated is exactly that at which all the ferrite and Fe_3C are in solid solution—that is, very slightly above the lines, *G–O–S* and *E–S*. This applies to the annealing of steel, as much as to the restoration of its valuable characteristics when they have been lost by over-heating. This restoration of minutest crystal-size is known as "refining," and too much cannot be said of its usefulness.

In Fig. 3, Plate XII, the writer has shown a photomicrograph of overheated steel, and, in Fig. 1, Plate XIII, the same steel refined by reheating to the temperature at which the solid solution was formed. The difference in size of structure will be evident at a glance.

The Burning of Steel.

When the over-heating of steel reaches a certain temperature, dependent on the carbon-content, its brittleness can be removed only slightly by "refining," either through heat treatment or mechanical distortion. Such steel becomes unsafe and worthless. It is only very recently that Stansfield,[80] in an able treatise, has shown what happens in this so-called "burning" of steel.

When steel, of any carbon-content, is heated to a temperature above the line, *A–a*, in Fig. 5, it shows the effect of having been burnt. The best method of manifesting this result is by microscopic examination. It has already been declared that steel between the lines, *A–B* and *A–a*, is in a condition partly liquid and partly solid. On being heated to within this area, the steel will begin to melt, and tiny drops of the most fusible portions will form in its interior. These most fusible particles are the portions highest in carbon. On melting, they will segregate to the lines of weakness of the steel, that is, the joints between the crystals. Stansfield thinks that steel which has not burnt beyond this point may be restored by suitable annealing at a high temperature, followed by "refining," but this is doubtful.

A second stage in burning occurs when the segregated liquid collects at the surface of the steel, and internal flaws form, which may be due to the irregular expansion of the steel, or to the evolution of gas in its now weak interior, or to cavities left by the liquid portion.

The third and last stage is due to formation of gas bubbles which break through the skin of the piece and project liquid steel from the mass. The flaws thus produced are oxidised by the atmosphere. Stansfield thinks that steel burnt to the second stage might be restored by heat treatment and forging, but that when the burning has proceeded to the third stage, there can be no remedy.

A photomicrograph of burnt steel is shown in Fig. 2, Plate XIII.

Porosity.

The study of blow-holes in steel has already led to very interesting results. In addition, there seem to be some conditions of manufacture or treatment whereby apparently sound steel will show under the microscope a structure honey-combed with gas cavities, and unfit for use. The relations between this kind of porosity and conditions of manufacture are not understood. In a magnified section of a piece of polished and unetched steel, the fracture exhibited evidence of porosity to the eye only after a most searching examination. The gas-cavities showed the traces of little brooks or feeders for gas into the main pool, which is a characteristic phenomenon of such porosity. It may not be manifested in the case of each blow-hole, but the writer has never known a case where some feeders could not be seen in every section examined.

Osmond gives a warning not to be led astray by irregularities due to polishing, and confuse such defects with either blow-holes or microscopic cracks ("checks").

Ridsdale[81] has made a first attempt at systematic study of this, and allied defects.

Part IV.—Addenda.

There are many others who have contributed most worthily to our knowledge of the metallography of steel, whom the writer has not quoted in the text, through lack of space and because, in the limited time permitted in which to prepare this compilation, it was impossible to cover the entire ground of the literature. Especially is this true of some of the writers in German, who have collected many data, increasing their value by philosophical interpretation or added material, or both.

Thus Ledebur, whose "Handbuch der Eisenhüttenkunde," is the acknowledged authority on the metallography of cast iron, and a valuable reference work on the metallography of steel, has published much information in current literature as well.[82-85] Jüptner, who, with others, has published, in the pages of the *Journal* of the Iron and Steel Institute, studies of the vexing problems arising in applying the phase rule to the solution theory of iron and steel (vexing especially in the case of cast iron), has published several valuable papers in German.[86-89] Vogel,[90] Martens,[91-93] Schüller,[94] and others whose papers are found in the journals devoted to iron and steel and allied sciences, should be read by the careful student of this subject, and the work of Heyn[95-102] should receive particular attention.

Ischewsky[103] proposes a method of etching with picric acid, which the writer has found of great usefulness, and the new pyrometer of Wanner[104] promises to extend the field of our investigations in metallography.

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TRANSACTIONS
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DISCUSSION ON
THE MANUFACTURE OF STEEL.

By Messrs. R. A. Hadfield, Albert Sauveur, Henry M. Howe,
Oswald Erlinghagen, William R. Webster,
J. P. Snow, William Metcalf
and Bradley Stoughton.

Mr. Hadfield.

R. A. Hadfield, M. Inst. C. E., Sheffield, England. (By letter.)— The writer has read with much interest Mr. Metcalf's valuable paper and congratulates most heartily the iron and steel industry of America upon the wonderful progress, so clearly set forth by Mr. Metcalf, which has been made during the last twenty years.

The points indicated regarding heat treatment are most important, and they cannot be too strongly emphasised. Mr. Metcalf has always laid great stress upon the careful handling of steel while in the melting, or other preliminary processes, and his persistent advocacy of care in this respect has borne good fruit. Happily, too, nowadays, by means of pyrometers we can work much more correctly in the heat treatment of steel, and, without doubt, this advance will lead to still greater strides in improving steel and widening its usefulness during the next decade.

Whilst, as Mr. Metcalf rightly points out, there are in practice many cases where scientific and delicate instruments cannot be used, there is no doubt that, as practical requirements present themselves, the makers of apparatus and instruments for determining high temperatures will improve or simplify them. Whilst rough billets or bars in the forge may not require watching with special accuracy,

Mr. Hadfield. the completed articles made from them must be treated with the utmost care, and it is here that the increasing value of pyrometers has been felt. For example, the bar from which a milling cutter has to be made, need not, up to that stage, be watched with special care, but the cutter in its finished form should be handled and dealt with in furnaces in which the aid of the pyrometer can be called in. The writer feels sure that Mr. Metcalf will agree on this point.

As regards the use of alloy steels, there is, no doubt, a wonderful future for them, but here again too much must not be expected; it is only by the gradual accumulation of knowledge and after most careful study of the properties of each type of alloy that material of real practical value is obtained. It is not by one experiment alone, or by the production of an odd specimen, but only by long and laborious research, and by noting and marking down the variations, that any result is obtained. The aid of the metallurgist, both in the laboratory and in the works, the physicist and engineer must all be called in before that stage is reached where it can be said that real advance has been made.

Mr. Sauveur. ALBERT SAUVEUR, Esq., Boston, Mass. (By letter.)—In his short paper on the manufacture of steel, Mr. Metcalf apparently questions the value of "science applied to steel making," his attack being more especially directed to the value of the microscope and pyrometer. Were such views expressed by a person of indifferent professional standing, they could be summarily dismissed on the ground of irresponsibility and, therefore, of carrying with them but little weight. Coming, however, as they do from a man who was a pioneer in the manufacture of crucible steel in the United States, and who has attained a prominent position in his profession, they are entitled to recognition. When the author entered into his successful career, the rule-of-thumb methods reigned supreme and most of the progress which he witnessed, and indeed to which he contributed, was accomplished by empirical methods. And let it be proclaimed to the full credit of these methods, that the advance made through their instrumentality has been very great indeed. But they have now yielded about all they were able to contribute to the art; they are well-nigh exhausted, and for the last decade or two, the progress recorded has been due to the intelligent application of the results of scientific methods, including the use of the pyrometer and microscope. The attitude of the author in this matter was also the attitude of those so-called "practical men" who some thirty years ago refused admittance to the chemist, on the ground, following the author's argument, "that Nature had supplied" the best analytical balance "in the trained eye." To-day these same men are reaping the rich harvest sown by the chemist,

but many have failed to appreciate the teaching which it implies, for it is still their present attitude toward pyrometry, metallography and, in general, toward all scientific methods which make for progress in all arts, but which fortunately cannot be seriously held back by their lack of appreciation. Mr. Sauveur.

Notwithstanding Mr. Metcalf's opinion that "any extensive use of the microscope and pyrometer in the mills is doubtful," and while these instruments may not be employed in his works, thousands of pyrometers and hundreds of microscopes are in daily use by manufacturers, workers and consumers of steel, and their number must increase because the course of progress cannot be stayed. The author offers, as supporting his views against the usefulness of the microscope, the fact that the structure revealed is that of "various spots of the size of a pin head." Quite so, and, similarly, the chemist uses only a few grammes of metal to determine the composition of ten, twenty, or fifty tons of steel. Do we deny on that account the value of his work? The author also tells us that there may be a "difference of 1 000° in the temperature of different parts of the same bar" and asks "at what part of such a bar shall a pyrometer be applied"? If this is an instance of the results of heat treatment conducted by rule-of-thumb methods, it presents a striking evidence of the urgent need of the application of pyrometers.

The author sums up his arraignment by the following statement:

"Nature has supplied the best pyrometer and microscope combined, in the trained eye, governed by good sense and sound judgment, and it is doubtful, if, for good work, these natural faculties will ever be improved upon by any instruments of man's devising."

Such a statement hardly demands refutation; it carries with it its own condemnation.

Henry M. Howe, Esq., New York City.* (By letter.)—Professor Stoughton seems to have presented this difficult subject at once happily, clearly and justly. Prof. Howe.

If a word may be added, it is as to the substances, austenite, martensite, troostite and sorbite. As the writer understands M. Osmond, austenite is the name which he gives to the solid solution of carbon in iron when it is above the critical line, *A, G-O-S-E* of Fig. 5, and he restricts it to this solution absolutely unchanged. In the very slow cooling (*e. g.*, annealing) of a carbon steel, this austenite decomposes and changes into a mixture of ferrite and cementite, but even in a rapid cooling this decomposition takes place to a greater or less degree. The presence of manganese or nickel lowers the temperature at which this change begins, or, in other words, lowers the line, *G-O-S-E*. But, so soon as this change has begun, the material can, as the writer understands M. Osmond,

*Professor of Metallurgy, Columbia University.

Prof. Howe. no longer be called austenite, even if, to take an extreme case, so slight a change has occurred that it cannot be measured.

To the discoverer of a species belongs clearly the right to give it a name, but not, in the writer's opinion, to attach unreasonable or confusing conditions to the use of that name. When felspar decomposes it turns gradually into kaolin; but it would seem to many unreasonable and confusing to insist that a felspar in which there was only a slight trace of decomposition must no longer be called felspar, but some other name. The series of products between pure undecomposed felspar on one hand and pure kaolin, resulting from total decomposition, might well be called mixtures of felspar and kaolin and, in spite of his veneration for M. Osmond's work and wisdom, the writer has reluctantly ventured to follow a similar procedure in case of the series of decomposition products between austenite at one end and the conglomerate of ferrite and cementite at the other. He freely admits that, in one case as well as in the other, the decomposition may later be shown to pass through definite stages representing definite chemical compounds; in which case, the series of decomposition products, as a whole, would be less simple, and might well contain such compounds; but, as a teacher and one bound to reduce the matter to the simplest terms within his reach, it has seemed to the writer much simpler and more reasonable for the present to regard the series of decomposition products which hardened, tempered and annealed steels collectively form, as a mixture of (1) the mother substance, austenite or solid solution; and (2) the end products of its decomposition, ferrite and cementite; leaving the intermediate stages of martensite, sorbite and troostite out of prominent view for the general reader. Should it be shown later that they are really definite stages representing definite chemical conditions, then it will be time to complicate the matter for the general reader by forcing them prominently upon his notice.

Thus, regarding steel when above the line, *G-O-S-E*, as pure austenite, and extremely slowly cooled steel as essentially a conglomerate of ferrite and cementite, the writer regards hardened steel as austenite with some ferrite and cementite which have formed in spite of the suddenness of cooling, and tempered steel as containing much less residual austenite and much more ferrite and cementite than are present in hardened steel, thanks to the greater opportunity for the decomposition of the austenite in the reheating for tempering. We may not be able to detect the ferrite and cementite in the hardened and tempered steel, because we may not be able to recognize the kaolin in slightly altered felspar. The intermediate conditions of martensite, sorbite and troostite are of great interest to the metallographist; at present the writer questions but does not deny their importance to the general reader.

Mr. Erlinghagen.

OSWALD ERLINGHAGEN, ESQ., Remscheid, Germany.—With reference to the testing of steel, the speaker would like to state that there is, to-day, in Germany, practically no test other than the mechanical test.

For structural steel, for example, the testing is usually restricted to tests of the tensile strength in the longitudinal and transverse direction of rolling of flat bars, profile steel and plates, and to bending tests for the cold and red-hot test pieces. The steel for rivets and screw-bolts is tested also for bossing.

The speaker wishes to use this opportunity to mention the latest experiments as to the strength of plates with ordinary and higher temperatures. Professor von Bach published the results of some of those experiments in the *Zeitschrift des Vereines deutscher Ingenieure*.* He tested fifteen plates and stated that:

1.—The average tensile strength increases up to about 390 and 570° fahr.;

2.—The average tensile strength decreases with temperatures higher than about 390 and 570° fahr.;

3.—The average elongations decrease up to about 210 and 390° fahr.;

4.—The average elongations increase again above temperatures of 210 and 390° fahr.;

5.—The average reduction of area decreases up to about 390 and 570° fahr.;

6.—These areas increase again above these temperatures.

According to these results it is necessary that for boiler-plates, steam conduits, etc., those strengths which the test pieces show under the higher temperatures and not those shown under ordinary temperatures should be considered.

Mr. Webster.

WILLIAM R. WEBSTER, M. AM. SOC. C. E., Philadelphia, Pa.—Mr. Metcalf in his paper refers to the importance of controlling the heat treatment in the manufacture of steel. He might also have referred to the importance of controlling the heat in the basic open-hearth furnaces, for by the use of low heat one gets rid of the phosphorus first and the steel is not liable to become injured by oxidation. On the other hand, if one uses high heat one is liable to get rid of the carbon first, and the steel becomes filled with oxide; that has been developed in the last ten years by the different works of the United States. They are now making as good basic Open-Hearth Steel as they are acid steel.

Mr. Metcalf might also have called attention to the heat treatment in the rolling or forging, that is, putting sufficient work in to give the silky material which is so much desired. If a large mass is heated too high, there will be a large grain in the steel, and this

* Nos. 35-36, August 27th, and September 3d, 1904.

Mr. Webster. is of as much importance as the preliminary heat which is referred to.

Professor Stoughton states:

"Moreover, the physical characteristics of steel seem to depend on those of the crystalline units and on their relations to each other. From this point of view, the constitution of steel is analogous to that of the crystalline rocks, *e. g.*, granite. An engineer having to make use of this material would not base a selection of variety on analyses of oxygen, silicon, sodium, aluminium, etc., but rather on crystalline composition; the proportion of quartz," etc.

Now that is hardly fair, as the granite has to be taken as it is found. If Professor Stoughton had to manufacture the granite, as the steel manufacturer has to manufacture his steel, he would be very glad to know the conditions controlling the manufacture of the granite, size of grain, etc. No one knows much about it. It is only since 1893 that any systematic effort has been made to show the relation between the chemical and physical properties of steel, and to-day every steel manufacturer in the country relies upon this relation and works the steel hot into the finished product without making any preliminary tests whatever. If the result in the material does not come out as expected, there is something the matter with the manner of working, or in the chemistry. The engineer uses these chemical requirements in his specifications and, therefore, he should know their relation to the physical properties of steel. For the microscopists to look down, as it were, on a matter which is a little indefinite, is going a little too far.

The size of the grain, as Professor Stoughton says, does govern the quality of the material, and the microscope shows it up to those who are familiar with it, but as yet they have never given the relation between the new method and the old. That is between the grain of a broken piece as seen by the eye, and as seen under a microscope. Some say that it cannot be shown, others think that it can. Take, for instance, two samples, nicked and broken, of steel which has been purposely overheated; one will show the coarse grain, and the other piece will show the fine grain. The other ends have been carefully polished, and with an ordinary magnifying glass of about three multiplications one can see distinctly the coarse and the fine grains; the speaker thinks that this is going to be the connecting link between the ordinary and the improved methods. He also thinks that it will be a valuable method of detecting the coarse grains in driving axles and other materials, in which every piece is not tested. In 1903, in referring to this matter, Mr. Metcalf suggested that on driving axles one could get a very easy test on each one by breaking the excess off with a wedge, that is, one-third or one-half of the axle, or something of that kind. That, of

course, would be better than the glass. The speaker hopes that the method proposed will be further developed. Mr. Webster.

Referring to the question which has been asked as to the effect of the difference of heat on the wearing quality of steel, the speaker thinks that he might answer it in another way. Consider the matter of putting in a low limit of manganese for boiler steel; if the manganese was low in the charge, it must have been taken up by oxide of iron, and if oxide of iron was left in the steel, it was not good material for flanging. In several cases where there has been trouble in locomotive boilers, in nearly every instance, it was found that the steel had very low manganese. So that care should be taken as to the use of such steel in flange plates. In the matter of corrosion, the purer the steel, the more the corrosion.

J. P. Snow, M. Am. Soc. C. E., Boston, Mass.—From the bridge engineer's standpoint, it is important that the effect of the heat treatment received by structural steel be known before shipment is made from the mills. The ordinary methods of testing by pulling specimens to rupture and by bending them to specified radii may or may not show up the ill effects of overheating. It is necessary to expose the grain of the metal in order to tell with certainty whether the steel is normal or not. The ordinary bending test is purposely arranged so as not to break the specimen and, hence, is not the proper test for examining the grain. A nick-bend seems to the speaker to be the proper means for determining this feature, and there seems to be no reason why it cannot be incorporated with our ordinary commercial testing. Mr. Snow.

In a short paper recently read before the American Society for Testing Materials, a method of making these tests was outlined by the speaker, that is simple, effective and cheap. The proposed method is to shear from the ordinary crop ends of plates and shapes, pieces large enough to secure a specimen 12 in. wide, nick it in a specified way, clamp it in a hydraulic vise and force the free end over by a roller operated by hydraulic power. A machine to hold the specimen and operate the roller for breaking over the free end will occupy very little space. It can be placed at the shipping end of the rolling mill, and the operation of shearing, nicking and breaking the specimen can be done very quickly; in fact, before the rolling heat has left the piece.

A wide specimen is chosen because it is deemed unfair to the manufacturer to depend upon a narrow sheared specimen. The hardening effect of the shear should not be assessed against the quality of the metal. If the edges are planed, too much time will be consumed before the result of the test can be known.

As Mr. Webster has just said, if the heat treatment and other features are proper, the grain will be fine, and if improper, it will be

Mr. Snow. coarse. The test here proposed will show which is the case, and the appearance of the grain will be the criterion for acceptance or rejection.

This test can be applied to plates, shapes and even rails, and will, it seems to the speaker, do more to assure the buyer and consumer of steel that the material is reliable and free from brittleness than more scientifically refined chemical and tension tests.

Mr. Metcalf. WILLIAM METCALF, PAST-PRESIDENT, AM. SOC. C. E., Pittsburg, Pa. (By letter.)—Professor Stoughton's admirable paper is the clearest and most complete statement of the new science of metallography, or perhaps more correctly, micrography, that has come under the writer's notice.

It is gratifying to one who has spent nearly fifty years in the practice and study of metallography to find that the minute and exact searchings with microscope and pyrometer confirm, as far as they have gone, the facts which have been the guides of the most careful steel workers for the last half century. The facts, therefore, that are given in this paper, are well worth the study of all engineers who are users of steel, and this means, practically, all engineers.

There are two statements in the paper that seem to require modification. On page 387, the author says, "Hardened steels are used for only an extremely small number of purposes, such as armor plate, burglar-proof safes, etc."

In view of the fact that hardened steel, and, more particularly, hardened and tempered steel, is used for almost innumerable purposes; and that the proper hardening and tempering of steel has become a fine art requiring long practice and rare good judgment and powers of observation to secure good work, it would appear that this statement should be changed. Many chapters and papers have been published on this subject, and next to the proper manufacture of steel, it ranks as the most important of all operations connected with the steel business.

On page 394, the author states:

"Even dangerously, over-heated steel abused in either of the ways just indicated (if not yet burnt) may be restored to its pristine high quality by reducing the coarseness of the structure to the minutest possible size."

And on page 395: "This restoration of minutest crystal-size is known as 'refining,' and too much cannot be said of its usefulness."

True to a certain extent; they are statements of fact that have been published over and over again, and always with this warning: "Over-heating is an operation of disintegration and it should be avoided with care, because no restored piece of steel is ever as good again as it would have been if it had not been over-heated."

Mr. Metcalf.

The word "refining," as applied here, is not in accordance with the ordinary usage of steel-makers; "restoring" is the proper word.* "Refining" applies in the art of hardening and tempering, and means the heating of any piece of steel to the exact temperature necessary to produce, when quenched, the finest grain possible; it is the one thing that all hardeners should aim to produce for almost all purposes, there are some exceptions noted in "Steel."

This refining is caught best in all steels, at the point where steel begins to show a farther rise in temperature, immediately after the apparent stoppage of rise of temperature called the point of recalescence. If steel is quenched during this suspension of rise of temperature, it will not be refined perfectly because the change of structure going on then is not quite complete. In other words, we must allow for lag.

This is one of the many facts that led to the conclusion that recalescence, or its reverse, is due to the breaking up of crystallization, causing absorption of heat, and immediately after this change is complete, quenching will cause the finest possible grain. An experienced temperer can catch this point very accurately; it shows by a sudden rise of temperature plainly to be seen by a practiced eye.

Like Woehler's celebrated experiments showing fatigue, this "warning" can be verified easily by simply repeating the over-heating and restoring a few times to destruction. Many pages could be written as to causes, but the statement has been published so often that it does not seem worth while to encumber this discussion with unnecessary alliteration.

It is a matter of surprise and sincere regret that in so able and complete a paper, no mention should be made of Professor John W. Langley's great work, and that there is no reference to him in the Appendix. With unlimited means at his disposal and with no limit to his time, Professor Langley worked diligently on the metallography of steel for more than ten years. His experiments on specific gravities threw more valuable light to engineers on the properties of steel than anything that has been published, unless it be Woehler's Law of Fatigue. They developed, too, the fact that hardening by quenching is continuous from quenching at 212 to 60° fahr., up to quenching dripping hot steel in cold water.

The hardening effect from low temperatures was confirmed by Professor S. P. Langley, of the Smithsonian Institution, by means of the most delicate magnetic tests. The facts may be stated thus: for every degree of sudden quenching, there is a hardening effect, and for every degree of increase of temperature with slow cooling, there is a softening effect. This being the case, it seems clear that

* See Glossary in "Steel: A Manual for Steel Users."

Mr. Metcalf. hardening and softening are not due to any changes in the iron to *alpha, beta,* or *gamma,* or to any changes in the condition of the carbon; such changes occurring only by comparatively great changes in temperature. This led to Langley's conclusion, stated modestly and with reserve, that "hardness is due to tension, probably molecular," and this conclusion led to a long-sought correct definition of hardness, *i. e.,* hardness (brittleness) is rigidity, immobility; and, softness (toughness) is ductility, mobility.

Langley also established the normal limit of saturation of carbon in iron at 0.90 to 1.00%, which has been confirmed by many recent investigators. He also first showed that oxygen may be occluded in steel, not as oxide; this also has been confirmed. Feeling sure of the pernicious effects of nitrogen in steel, he showed by very beautiful tests on numbers of pieces that Bessemer steel contained the highest percentage of nitrogen; Open-Hearth steel, the next highest, and Crucible steel the lowest percentage.

He also showed that Bessemer steel of a known percentage of nitrogen lost very little nitrogen when remelted in a crucible, thus giving one reason why the cheaper steels, when remelted in a crucible, will not yield as good results as wrought iron of even composition, similarly melted.

He also reached the conclusion, stated, however, with great reserve, that steel in its best condition contains its carbon in solution rather than in combination. He did not deny the existence of Fe_3C, which was then a moot question, since clearly established, but claimed that all the facts led to the inference that solution of carbon was the condition when steel was at its best; the writer has always believed this to be true, and it seems to be confirmed in Professor Stoughton's paper.

Langley's specific gravity tests were published in 1877 in the *Transactions* of the American Association for the Advancement of Science, and later in a number of other publications.

Many of his results are given by the writer in the *Transactions* of the American Society of Civil Engineers, simply because, owing to his modesty and his high sense of honor, he was doing his work for others, he would not appear as author. It cannot be assumed that Professor Stoughton, being a teacher of metallurgy and metallography, is unacquainted with this work, and it seems to be a fair conclusion that Langley's work is not included, because, although he is certainly an able metallurgist, he is not a micrographer. That he did not use the microscope is due to the fact that when he was laying out his long-continued scheme of work, he consulted one of the ablest and most prominent physicists in the United States, who advised him that a microscope would be useless, because it could not magnify perspective, and that what he thought he saw would

not be that which was actually there. He yielded to this opinion, and the microscope was discarded. Mr. Metcalf.

Mr. Sauveur seems to feel aggrieved at the writer's remarks as to the limitations of the microscope and pyrometer, and assumes that he favors "rule of thumb" to science. In this he is mistaken; proper heat treatment is of vital importance, and it is the life study and life practice of every steel maker who knows his business and tries to conduct it properly. Also the steel makers preach heat treatment constantly and persistently to the steel users, and apparently to little purpose; it is so much easier to be careless, ruin a piece of fine and expensive work, swear that they used only a "cherry heat," and damn the steel as worthless. If the advocates of the pyrometer and microscope can heal only a little of this trouble, by inducing more care, the steel makers will hail them as deliverers and bless their work.

To illustrate, the writer recently examined two dies engraved beautifully at a cost of $150, both of which were broken, the steel worthless, and the die-maker angry. The steel was perfectly sound and good; the dies had been heated evenly to exactly the right temperature; they had not been heated through, they had been hardened over a comparatively cold hard center, and the strain had broken them. The fracture tells this story so perfectly and at a glance that no microscope could add anything to the knowledge of the case. A pyrometer would have shown the heat to be exactly right, but how could it have shown that the heat was only superficial? The writer thinks that Mr. Hadfield will agree with him in saying that no pyrometer could have kept that operator from blundering.

Again, the eye is after all the microscope of first instance, and every metallographer is limited to what his eye tells him, no matter what power he uses; is his use of the eye through the machine "science," and the skilled worker's use of his eye unaided "rule of thumb?" Again as to the pyrometer: Nature has provided that every temperature of heated steel has its own distinctive color modified slightly for various quantities of carbon present; these colors are as fixed and as sure as the law of gravitation; is the steel-worker who knows and uses this beautiful law a "rule-of-thumb" blunderer, while the man who reads a pyrometer and cannot see by this absolute guide is a "scientist?" The pyrometer and microscope have their uses, great uses, and so has chemical analysis, all in the proper place, the laboratory, and there the intelligent steel-worker goes to get guiding information; but who ever heard of carrying chemical apparatus out into the mill?

The writer's sole argument is to emphasize the importance of, and the necessity for, brains applied with experience and sound

Mr. Metcalf. judgment. It seems as if some gentlemen attach more importance to machines than to brains. That is apparently the only difference.

Prof. Stoughton. BRADLEY STOUGHTON, ESQ., New York City.* (By letter.)—Answering Mr. Metcalf, who says:

"There are two statements in the paper that seem to require modification. On page 387, the author says, 'Hardened steels are used for only an extremely small number of purposes, such as armor plate, burglar-proof safes, etc.'

"In view of the fact that hardened steel, and more particularly hardened and tempered steel, is used for almost innumerable purposes; and that the proper hardening and tempering of steel has become a fine art requiring long practice and rare good judgment and powers of observation to secure good work, it would appear that this statement should be changed. Many chapters and papers have been published on this subject, and next to the proper manufacture of steel, it ranks as the most important of all operations connected with the steel business."

The writer admits Mr. Metcalf's statement for "hardened and tempered" steels, but, in using the words, "hardened" steels, he especially desired to exclude steels which had been tempered. At this point he was discussing martensite, which occurs in hardened steels, but probably does not ever occur in hardened and tempered steels. He is well aware that hardened and tempered steels are of very great importance in all kinds of engineering work, but thinks that Mr. Metcalf will agree with him that hardened steels, untempered, are used only for an extremely small number of purposes. What Mr. Metcalf has said of the importance of proper hardening and tempering is indeed true.

The writer is very much obliged to Mr. Metcalf for calling his attention to the use of "restoring" instead of "refining" for production of the minutest crystal-size by heat treatment. The term "refining" is used so much in textbooks in this connection that the writer has fallen into the way of using it a great deal. He does not think that restoring is intrinsically superior to refining as a term to express the treatment in question, but refining is used in another sense in the metallurgy of steel, so that the use of restoring here is perhaps less likely to be confusing.

Mr. Metcalf regrets that, in the writer's paper, no mention has been made of Professor John W. Langley's great work, and that there is no reference to him in the Appendix. At this point, attention should be called to the fact that the list of references at the end of the paper is not intended in any sense as a bibliography. A bibliography of the metallography of steel would be very much more comprehensive than the articles there mentioned, which are merely the papers to which reference has been made in the text of the paper. The list includes many important papers on this subject, because the writer has had occasion to refer to them in his remarks,

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Prof. Stoughton.

but it does not include, by a good share, all the papers that are of importance in this connection, nor all which he consulted in making up his notes. The reader will find in Vol. I of *The Metallographist* a Bibliography of the Metallography of Iron and Steel, compiled with great care and skill, and a continuation of this bibliography may be found in succeeding volumes.

The writer joins with Mr. Metcalf in regretting that no mention is made in the body of the paper of Professor Langley's work, and adds his regrets that no mention is made there of Mr. Metcalf's great work, which has both scientific and practical value, on the metallography of steel. The reason for both these omissions is the same. It is not because Professor Langley and Mr. Metcalf did not work with the microscope. As the writer has said (page 360):

"Microscopic examination is not the whole of metallography, and the microscope is seldom, if ever, sufficient unto itself, but more often a useful aid to other branches of investigation."

At the present time, microscopic examination is occupying a great part of the attention of metallographers, probably for several reasons: (1) it is new; (2) several valuable and striking discoveries have been made with the aid of the microscope, which encourages others to follow this line of work; (3) it can be used to advantage, and results obtained, without having that so-called "practical knowledge" which can be acquired only by long and patient experience; and (4) once having learned how to use the microscope, one can discover a good many facts in a short time. These reasons do not, in the writer's opinion, place microscropy on a higher plane than any other branch of metallography, but a discussion of the "Metallography of Steel," which was supposed to cover the ground of the past ten years, must necessarily devote more attention to microscopy than to any other branch, because more work has been done by metallographers in that line.

Much of Professor Langley's work was presented to the world in books or papers by Mr. Metcalf,[105-109] or by joint papers of Langley and Metcalf.

Besides Professor Langley's work, which Mr. Metcalf mentions, the writer would add a line on his work (partly with the co-operation of Mr. Metcalf) on the specific gravity of steels, varying in carbon and quenched from different temperatures from a white heat, or slowly cooled.[107] Also on the lowering of specific gravity by cold working, a fact contrary to what we might have expected. He also devised an apparatus for testing the hardness of steel by means of a weighted diamond drill,[108] studied the diffusion of carbon into iron,[110] and the effect of aluminum on steel.[111] Together with Mr. Metcalf he holds a theory for the hardening of steel which has much to recommend it. In brief it says: "Hardness is due to high tension, probably molecular, and softness is absence of tension."*

*See p. 384 of No. 110, and pp. 149-150 of No. 106.

Prof. Stoughton. This theory is not dissimilar to that held by A. Le Chatelier and H. E. Field (page 363). As Mr. Metcalf has pointed out (*loc. cit.*) this theory explains why quenching sometimes ruptures steel, and is in simple accordance with the phenomena of tempering. It has this fact also in its favor: That austenite (by definition, the solid solution of iron and carbon) is not so hard as martensite (by definition, the partially decomposed solid solution, which should, therefore, be in a state of greater molecular tension, due to its transitory condition). In accepting this explanation, we should remember, however, that austenite and martensite are solid solution and partially decomposed solid solution, by definition only; as yet we lack the positive proof of their exact nature.

As to the work of Mr. Metcalf, it extends over too long a time, and too large a variety of subjects, to be included altogether in a brief summary such as this paper. Mr. Metcalf himself presented a paper on steel to this Congress, and the writer had hoped that, in this paper, he would cover in part the ground which he has so ably covered before, and include a summary of his work and Professor Langley's. He has confined himself, however, to another subject. A few additional words here as to his work will, therefore, not be out of place.

The reader's attention is especially called to "Steel; A Manual for Steel Users,"[106] which contains the most recent information on those little-understood impurities in steel, oxygen, hydrogen and nitrogen, and is, in the writer's opinion, the best condensed manual on the treatment of steel.

A word here is also desirable in regard to the "Metcalf Test," which the writer insists that every student working under him in the laboratory shall understand at the commencement of his work on steel. If a bar of steel be nicked all around at a low red heat, at intervals of $\frac{1}{2}$ to $\frac{3}{4}$ in., and then one end be placed in a very hot fire, leaving the other end sticking out, it may be heated to a scintillating heat at one end, with a gradual drop in temperature to black heat at the other end. Obviously, the bar will be burned at the hot end, and at some point or other it will be exactly restored. If, as soon as heated throughout, it be quenched in cold water until cold, and then wiped dry, all gradations of hardness will be shown from glass hardness, at the hot end, to the softness of ordinary rolled steel at the cold end. Furthermore, there will be a sudden drop in hardness from the point which was exactly at the restoring temperature when quenched to the point which was just below that temperature. In other words, the steel was not sensibly hardened except where it was quenched at a temperature at, or above, the restoring temperature. If, now, the bar be broken at the places where it was nicked, and the fractures examined, all gradations in frac-

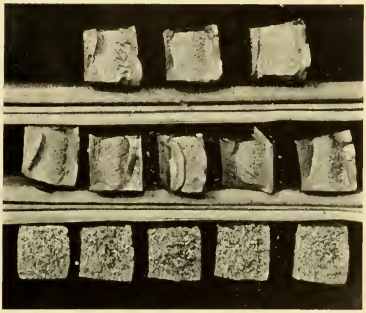
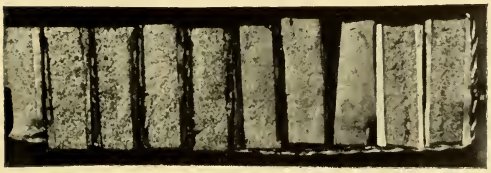


FIG. 1.—0.47 C. STEEL, SLOWLY COOLED.



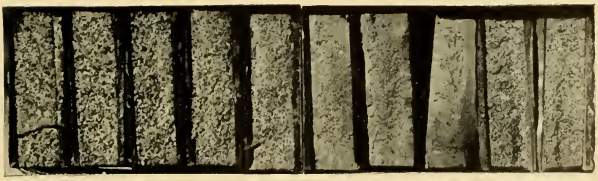


FIG. 2.—0.70 C. STEEL, QUENCHED IN COLD WATER.

ture will be observed, from burned steel at the hot end, to the finest fracture of all at the point where the structure has been restored, and increasing again in crystal-size to that of the rolled steel. The fractures of bars so treated are shown in Figs. 1 and 2, Plate XIV. For these photographs, the writer is indebted to Mr. T. M. Phetteplace, a graduate student in his laboratory. Although on a smaller scale, they compare not unfavorably with a similar photograph published by Mr. Metcalf when he originally described this very interesting test.[112] Prof. Stoughton.

Answering Mr. Webster: It is not clear to the writer whether he suspects that he would not "be very glad to know the conditions controlling the manufacture of the granite, size of grain, etc." Substituting the word steel for granite, the writer would indeed be glad to know all that he could on this subject. It is far from his point of view to be in a position of looking down "on a matter which is a little indefinite." Mr. Webster says that the microscope has not yet shown the relation between the size of the grain, as viewed by the microscope and as indicated in the fracture. The writer is now working with Mr. Webster on this very question, and would be glad if the results could be discussed here, but, unfortunately for this hope, the experiments have not yet quite reached the stage where publication of them is desirable, so they must be left for a later communication.

AMERICAN SOCIETY OF CIVIL ENGINEERS,

INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

CONCRETE AND CONCRETE-STEEL.

Congress Paper No. 70.

CONCRETE AND CONCRETE-STEEL IN THE UNITED STATES.

By Edwin Thacher, M. Am. Soc. C. E., New York City, U. S. A.

Congress Paper No. 71.

CONCRETE AND CONCRETE-STEEL IN THE UNITED STATES.

By John S. Sewell, Capt., Corps of Engrs., U. S. A., Washington, D. C., U. S. A.

Congress Paper No. 72.

CONCRETE AND CONCRETE-STEEL IN FRANCE.

By A. Considère, Inspecteur Général des Ponts et Chaussées, Paris, France.

Congress Paper No. 73.

CONCRETE AND CONCRETE-STEEL IN HOLLAND.

By J. J. L. Bourdrer, C. E., The Hague, The Netherlands.

Congress Paper No. 74.

CONCRETE-STEEL BRIDGES.

By Dr. Fritz von Emperger, C. E., Vienna, Austria.

Discussion of the Subject by

W. W. Christie, Paterson, N. J., U. S. A.
Albert W. Buel, New York City, U. S. A.
R. J. Gifford Read, London, England.
F. Schüle, Zurich, Switzerland.
Richard L. Humphrey, Philadelphia, Pa., U. S. A.
J. L. Van Ornum, St. Louis, Mo., U. S. A.
Oswald Erlinghagen, Remscheid, Germany.
Robert W. Lesley, Philadelphia, Pa., U. S. A.
Charles G. Darrach, Philadelphia, Pa., U. S. A.
A. N. Talbot, Urbana, Ill., U. S. A.
Gardner S. Williams, Ann Arbor, Mich., U. S. A.
William B. Fuller, New York City, U. S. A.
Rudolph P. Miller, New York City, U. S. A.
Oscar Lowinson, New York City, U. S. A.
G. N. Knapp, Madison, Wis., U. S. A.
H. F. Dunham, New York City, U. S. A.
E. P. Goodrich, New York City, U. S. A.
J. B. Marsh, Des Moines, Iowa, U. S. A.
Augustus Smith, New York City, U. S. A.
Frank Beckwith, Cleveland, Ohio, U. S. A.
W. K. Hatt, Lafayette, Ind., U. S. A.
A. L. Johnson, St. Louis, Mo., U. S. A.
Sanford E. Thompson, Newton Highlands, Mass., U. S. A.
W. D. Pence, Lafayette, Ind., U. S. A.
C. A. Wentworth, Guantanamo, Cuba.
E. M. Scofield, Philadelphia, Pa., U. S. A.
Sidney B. Williamson, New York City, U. S. A.
Edwin Thacher, New York City, U. S. A.
John S. Sewell, Washington, D. C., U. S. A.
Dr. Fritz von Emperger, Vienna, Austria.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 70.

CONCRETE AND CONCRETE-STEEL.

CONCRETE AND CONCRETE-STEEL IN THE UNITED STATES.

By Edwin Thacher, M. Am. Soc. C. E.

In preparing a paper on this subject the writer does not understand that he is expected to dwell at any great length on details or theory, but to give a general summary of the development of concrete and concrete-steel construction, a record of important facts gained by experiment or experience, and a summary of present practice.

Nothing can give a better idea of the growth and magnitude of concrete and concrete-steel construction in the United States during the past ten or twenty years than an inspection of Table 1 and the diagram, Fig. 1, showing the quantity of cement consumed.

It will be seen that the total production of Portland cement in the United States in 1902 was upwards of 17 000 000 barrels, or 31.5 times greater than in 1892. The total consumption of domestic and imported Portland cement in 1902 was upwards of 19 000 000 barrels, or nearly 6.5 times greater than in 1892. The total consumption of Portland and Natural cement in the United States in 1902 was upwards of 27 000 000 barrels, or 2.44 times greater than in 1892.

TABLE 1.—Cement Consumed in the United States During the Past 20 Years.

Year.	Portland Cement. (Barrels.)			Natural Cement, barrels.	Total Portland and Natural Cement, barrels.	Percentage gain or loss each year over preceding year.		
	American.	Foreign.	Total.			Portland Cement.	Natural Cement.	Total Cement.
1883.....	90 000	486 418	576 418	4 190 000	4 766 418	.....	.....	.....
1884.....	100 000	585 768	685 768	4 000 000	4 685 768	+ 19.0	— 4.5	— 1.7
1885.....	150 000	554 396	704 396	4 100 000	4 804 396	+ 2.7	+ 2.5	+ 2.5
1886.....	150 000	650 032	800 032	4 186 152	4 986 184	+ 13.6	+ 2.1	+ 3.8
1887.....	250 000	1 070 400	1 320 400	6 692 744	8 013 144	+ 65.0	+ 59.9	+ 60.7
1888.....	250 000	1 835 504	2 085 504	6 253 295	8 338 799	+ 58.0	— 6.6	+ 4.1
1889.....	300 000	1 740 356	2 040 356	6 531 876	8 572 232	— 2.2	+ 4.5	+ 2.8
1890.....	335 500	1 940 186	2 275 686	7 082 204	9 357 890	+ 11.6	+ 8.4	+ 9.2
1891.....	454 813	2 988 313	3 443 126	7 451 535	10 894 661	+ 51.3	+ 5.2	+ 16.4
1892.....	547 440	2 440 654	2 988 094	8 211 181	11 199 275	— 13.2	+ 10.2	+ 2.8
Total for 10 years	2 627 753	14 292 027	16 919 780	58 698 987	75 618 767	.....	.....	.....
1893.....	590 652	2 674 149	3 264 801	7 411 815	10 676 616	+ 9.3	— 9.8	— 4.7
1894.....	798 757	2 638 107	3 436 864	7 563 488	11 000 352	+ 5.3	+ 2.0	+ 3.0
1895.....	990 324	2 997 395	3 987 719	7 741 077	11 728 796	+ 16.0	+ 2.4	+ 6.6
1896.....	1 543 023	2 989 597	4 532 620	7 970 450	12 503 070	+ 13.7	+ 3.0	+ 6.6
1897.....	2 677 775	2 090 924	4 768 699	8 311 688	13 080 387	+ 5.2	+ 4.3	+ 4.6
1898.....	3 692 284	2 013 818	5 706 102	8 418 924	14 125 026	+ 19.7	+ 1.3	+ 8.0
1899.....	5 652 266	2 108 388	7 760 654	9 868 179	17 628 833	+ 36.0	+ 17.2	+ 24.8
1900.....	8 482 020	2 386 683	10 868 703	8 383 519	19 252 222	+ 40.0	— 15.0	+ 9.2
1901.....	12 711 225	939 330	13 650 555	7 084 823	20 735 378	+ 25.6	— 15.5	+ 7.7
1902.....	17 230 644	1 994 787	19 225 431	8 044 305	27 269 736	+ 40.8	+ 13.5	+ 31.5
Total for 10 years	54 368 970	22 833 178	77 202 148	80 798 268	158 000 416	.....	.....	.....

Slag cement manufactured from 1900 to 1902 inclusive..... 1 116 855 barrels.
Cement exported from 1897 to 1902 inclusive..... 838 205 barrels.

The production of Portland cement in the United States has had a constantly increasing growth for the past twenty years. It has exceeded the amount imported since 1897, and has exceeded the production of Natural cement since 1900; and in 1902 its production was 2.14 times greater than that of Natural cement. The number of Portland cement factories has increased from 16, in 1890, to 65, in 1902, while the number of Natural cement factories has fallen off from 76, in 1898, to 62, in 1902.

Portland cement was invented by Joseph Aspden, of England, in 1813, but was not used in large quantities until many years later. Up to 1883, or 70 years after its discovery, the total consumption in the United States was less than 1 900 000 barrels. For the next fifteen years, or up to 1898, the annual increase in consumption was quite uniform, and in that year it reached 5 706 000 barrels. From 1898 up to the present time the increase in consumption

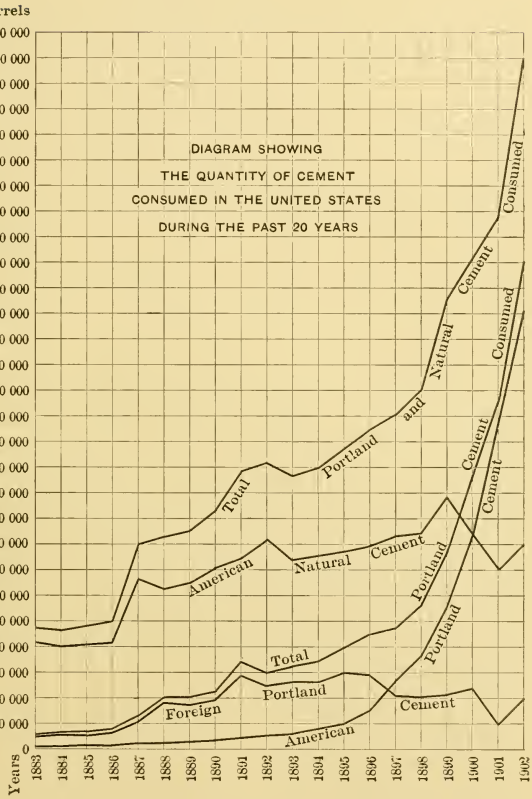

Barrels
28 000 000
27 000 000
26 000 000
25 000 000
24 000 000
23 000 000
22 000 000
21 000 000
20 000 000
19 000 000
18 000 000
17 000 000
16 000 000
15 000 000
14 000 000
13 000 000
12 000 000
11 000 000
10 000 000
9 000 000
8 000 000
7 000 000
6 000 000
5 000 000
4 000 000
3 000 000
2 000 000
1 000 000
0
DIAGRAM SHOWING
THE QUANTITY OF CEMENT
CONSUMED IN THE UNITED STATES
DURING THE PAST 20 YEARS
Total Portland and Natural Cement Consumed
American Natural Cement
Portland Cement Consumed
Total
Portland Cement
Foreign
Portland Cement
American
Years
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902

Fig 1.

has been very rapid. The statistics for 1903 have not yet been published, but the consumption will probably exceed 22 000 000 barrels.

The rotary kiln was invented by Frederick Ransome, of England, in 1885, but has been perfected and made a commercial success in the United States. In 1893 rotary kilns were used in the manufacture of 25.2% of the Portland cement produced in the United States, and in 1900 this had increased to 81.5 per cent. The cement consumed in the United States during the year 1902, estimating 1 barrel of cement to 1 cu. yd. of concrete, was sufficient to build a wall 1 000 miles long, 20 ft. high and 7 ft. thick.

During the past ten years an immense amount of concrete has been used by the United States Government in the construction of locks, dams, breakwaters, fortifications, buildings and other public works, concerning which Captain John S. Sewell, Corps of Engineers, U. S. A., who has prepared a paper for the International Engineering Congress, is much better qualified to speak than the writer. Very large quantities of concrete have also been used in the public works of all our large cities, and in the subways of New York, Boston and Philadelphia; for piers, retaining walls, concrete and concrete-steel bridges; foundations, pavements, vault lights, walls, floors, columns and roofs of buildings; reservoirs, tanks, cisterns, aqueducts, chimneys, and, in fact, nearly every branch of engineering and architectural construction. It is rapidly superseding wood, steel and stone for a great variety of uses for which these materials had, for many years, held an undisputed field, and the remarkable increase in the use of concrete during the past few years shows not only that it has many advantages over other materials of construction, but that the public at last has been educated to see and acknowledge it.

Buildings.—Concrete-steel buildings have been rapidly gaining in favor during the past few years, and are superseding, to some extent, steel-skeleton construction for tall buildings.

Ernest L. Ransome, Assoc. Am. Soc. C. E., has undoubtedly done more than any other engineer, and probably more than all others, to promote the construction of concrete-steel buildings in the United States, and most of the buildings of this character, thus far constructed, have been of the Ransome system. Some of the most important are as follows:

The Pacific Coast Borax Factory at Bayonne, N. J., a portion of which, 75 by 200 ft., is of four stories, and the remainder, 175 by 200 ft., is of one story, of reinforced concrete; the wall faces were dressed with a pneumatic hammer.

The St. James Episcopal Church, Brooklyn, N. Y., a handsome structure, 140 by 90 ft., with walls 23 ft. high, dressed in imitation of rock-faced masonry.

The Nassau County Court House and Jail, Mineola, N. Y., in which the walls, floors, columns, partitions and dome are of reinforced concrete throughout.

An office building for Hamilton and Colbert, Washington, D. C., 93 by 31 ft., seven stories, 80 ft. high above the sidewalk.

The tank building, 112 by 140 ft., and dry kiln building, 52 by 89 ft., for the Singer Manufacturing Company, Cairo, Ill.

The Robert A. Van Wyck Laboratory, entirely of concrete steel, the first to be erected in New York City.

The College Fraternity Building, New Haven, Conn.

The residence of F. Tiedeman, St. George, Staten Island, N. Y.

The Ingalls Building, Cincinnati, Ohio, 100 by 50.5 ft.; height from sidewalk to cornice, 210 ft. This building has sixteen stories besides basement, sub-basement and attic, and is the boldest example of such construction yet erected. The first three stories are faced with marble; above this, the facing is of glazed brick with terra cotta trimmings. Elzner and Henderson were the architects, and the Ferro Concrete Construction Company of Cincinnati were the contractors.

Many other buildings of the Ransome system have been built, or are now under construction.

Concrete Blocks.—Litholite, or concrete castings made in sand moulds patented by C. W. Stevens, of Harvey, Ill., has been used to a considerable extent for the facing of buildings and other structures, and can be cast into highly ornamental shapes with the same facility as metal. It was used for facing the first and second stories of a building, corner Nassau and Beekman Streets, New

York City, for the walls of a three-story building in Harvey, Ill., and in other localities.

Harmons S. Palmer, Washington, D. C., manufactures a machine for making hollow concrete blocks of all sizes for building purposes, and claims to be the originator of the hollow-block system. These blocks have been used quite extensively in buildings of various kinds.

The Normandin cement concrete construction block machine, manufactured at Jackson, Mich., makes hollow concrete blocks which are used for the walls of buildings and other purposes. Blocks are made of any desired form, or color, and give an attractive, durable, economical and fire-proof wall.

Concrete blocks for hollow walls are made by the American Hydraulic Stone Company of Denver, Colo. They were used in the walls of the Hotel Angelus (four stories) at El Paso, Tex., for a three-story office building at Milwaukee, Wis., and other buildings.

The Winget Concrete Machine Company of Columbus, Ohio, manufactures a machine for making hollow concrete blocks for building purposes.

A machine for the manufacture of cement pipe in place was invented by Martin and Ormond of Riverside, Cal., in 1899, and in 1900, 75 000 ft. of pipe, from 4 to 20 in. in diameter, were made. The machine will put in 1 000 ft. of pipe or flume in a day of 10 hours.

Foundations.—The largest concrete foundation built during the past ten years is one for a ferry house in San Francisco, Cal., built in 1895.

It consists of 111 concrete piers on pile foundations connected by groined arches. The dimensions of this floor are 160 by 670 ft., and 36 000 barrels of cement were used in its construction.

Chimneys.—Many notable concrete-steel chimneys have been built during the past ten years. One for the Pacific Coast Borax Company, Bayonne, N. J., 150 ft. high and 7 ft. inside diameter. One for the Central Lard Company of New York, at Jersey City, N. J., 108 ft. high and 8 ft. inside diameter. One for the Pacific Electric Railway Company at Los Angeles, Cal., built in 1902. It has a height of 158.5 ft. above grade and 174 ft. above the foundation, and has an inside diameter of 11 ft. This is believed to be

the highest concrete-steel chimney in the world. All these chimneys have hollow walls of the Ransome type, reinforced horizontally and vertically. A chimney built by Mr. Carl Weber for the Laclede Fire Brick Manufacturing Company of St. Louis, Mo., in 1903, has a height of 130 ft., and an inside diameter of 5 ft., and is reinforced horizontally and vertically with steel T-bars. The walls are hollow for a height of 65 ft. A similar chimney was built for the new Leiter coal mines at Zeigler, Ill., and completed May 1st, 1904. It has a height of 154 ft. 10 in., and an inside diameter of 6 ft., with hollow walls for a height of 51 ft.

Grand Stands.—Concrete-steel construction is becoming popular for grand stands. One was completed this year on the athletic field of Washington University, St. Louis, Mo. It has a length of 792 ft., and will seat 9 000 people. Another was built in 1903 on the athletic field of Harvard University. It is U-shaped, 573 ft. long and 420 ft. wide, and will seat from 21 000 to 26 000 people.

Street Railroads.—Concrete has been used for the foundations of street railroads in Kansas City, Mo.; Scranton, Pa.; Detroit, Mich.; Toronto, Ont., and other cities.

Cross-Ties.—Concrete-steel cross-ties are being used in an experimental way on the Pere Marquette, Lake Shore and Michigan Southern, Pennsylvania, Michigan Central, and other railroads, and if they prove to be a success, very large quantities of cement will be used in their manufacture.

Roadbeds, Railroads.—Longitudinal stringers of concrete-steel, united at frequent intervals by cross-struts of the same material, have been tried to replace cross-ties, a wooden cushion being used between the rails and stringers. Continuous roadbeds of concrete have also been used. A section, 1 200 ft. long and 8 ft. wide, trough-shaped, 18 in. thick for width of track and 26 in. thick at ends, was laid in the yard of the Long Island Railroad Company at Jamaica, N. Y., in 1900. A 2-in. plank is used under the rails as a spiking piece. This track is giving good satisfaction.

Reservoirs.—Concrete has been used to a large extent for many years in the construction of reservoirs, but not until recently has concrete-steel been used for this purpose. The Louisville Water Company, Louisville, Ky., completed in 1900 a clear-water reservoir, 394 by 460 ft. and about 25 ft. high. The walls and columns were

concrete, and the roof concrete-steel groined arches of about 19 ft. clear span. A reservoir is now under construction for East Orange, N. J., 139 by 240 ft. and 22 ft. 4 in. high, in which the walls, columns and roof are to be of concrete-steel throughout.

Dams.—Concrete-steel construction is coming into extensive use for dams. Tucker and Vinton, of New York City, built in 1903 an arched concrete-steel dam at Ithaca, N. Y. This dam has a height of 30 ft. 9 in. above the bed of the stream, and is reinforced on intrados and extrados with longitudinal bars interlaced with wire mesh. The Upper Otay Dam of the Southern California Mountain Water Company, completed in 1900, is an arched concrete-steel dam, 350 ft. long and 84 ft. high, reinforced with steel plates and steel cables. Amburson and Sayles of Watertown, N. Y., built in 1903 a hollow concrete-steel gravity dam at Theresa, N. Y. It is 120 ft. long and 11 ft. high. It consists of concrete buttresses, 12 in. thick, connected by a concrete toe and concrete-steel slabs. A large number of dams of this construction are now under contract.

Tunnels.—Concrete is being used in large and increasing quantities for tunnels. Large quantities were used in the construction of the East Boston Tunnel under Boston Harbor, and immense quantities will be used in the great Pennsylvania Railroad Tunnel, 30 000 ft. long, under the North and East Rivers and the City of New York.

Street Pavements.—Concrete has been used to some extent for the pavements of city streets, and so far as the writer can learn has given satisfaction wherever used. Several years ago the writer visited Bellefontaine, Ohio, for the purpose of inspecting some concrete street pavements in that city, laid three or four years previously. The pavements were in almost perfect condition, and so satisfactory in every way that concrete was adopted for the pavement of the large cantilever bridge across the Tennessee River in Knoxville, Tenn. Mr. H. L. Weber, City Civil Engineer, Richmond, Ind., gives an interesting description* of the concrete street pavements in that city, and says they stand up well under heavy traffic, and are not more slippery than brick, asphalt or Macadam pavements.

Cribwork.—Concrete-steel cribwork is being used quite exten-

**Engineering News*, Vol. LI, p. 84.

sively in Canada. It is being used at Depot Harbor, Ont., in the construction of a wharf, 400 ft. long and 150 ft. wide, and will be used at Port Colborne, Ont., for the construction of a breakwater, 2 400 ft. long. Its inventor and patentee, Mr. T. W. Frazer, of the Canadian Department of Public Works, stated to the writer that it costs very little more than timber cribbing, and, at Depot Harbor, had been substituted therefor by the contractor without extra compensation. It is built in essentially the same way as timber cribbing with exposed surfaces solid, and interior filled with rock or earth.

Bins.—Concrete-steel is being used in the construction of bins for the storage of grain, cement, coal, etc. The new grain elevator plant of the Canadian Pacific Railroad, at Port Arthur, Ont., has nine bins of concrete-steel, 30 ft. in diameter and 90 ft. high. The walls are 9 in. thick, reinforced horizontally and vertically; there are also four intermediate bins, the thirteen bins having a total capacity of 443 000 bushels. There was a failure of concrete-steel grain bins in Duluth, Minn., in 1900. The bins were 104 ft. high and 33 ft. 6 in. in diameter. The failure was clearly due to faults in design, which are not likely to be repeated. The Illinois Steel Company have built at South Chicago, Ill., four concrete-steel bins, 25 ft. in diameter and 50 ft. high, for the storage of cement. The walls are from 5 to 7 in. thick, reinforced by the Monier system.

Tanks and Stand-Pipes.—Concrete-steel construction is being used to an increasing extent in the construction of tanks for water, ammonia, wine and other fluids, and for stand-pipes. In 1903 a water tower was constructed at Fort Revere, Mass., for the United States Government. The tower is 93 ft. high, of octagonal section, inclosing a tank, 20 ft. in diameter and 50 ft. high, Hennebique construction. The tank has a thickness of 6 in. at the bottom and 3 in. at the top, coated on the inside with 1 in. of 1:1 Portland cement mortar, and is water-tight. A stand-pipe was recently erected at Milford, Ohio. It has a height of 81 ft. and an outside diameter of 15.5 ft. The shell is composed of 1:3 Portland cement mortar from 5 to 9 in. thick, reinforced with T-bars. Two tanks and a 50-ft. chimney of concrete-steel were recently completed by Robert A. Cummings, M. Am. Soc. C. E., at Hampton, Va. The tanks have a height of 16 ft. and an inside diameter of 26 ft. 6 in. The walls are 1:2:4 concrete, 12 in. thick, reinforced with steel bars. The

tanks were plastered with 1:2 mortar, to which was added a solution of caustic potash and alum, and are perfectly water-tight.

A water tank,* 10 ft. in diameter and 43 ft. high, built in 1899 by William B. Fuller, M. Am. Soc. C. E., at the filtration works of the East Jersey Water Company, Little Falls, N. J., has some remarkable features. It is reinforced concrete, 15 in. thick at the bottom and 10 in. thick at the top. The entire tank was built in eight hours, and is a perfect monolith, all concrete being dropped from the top, or 43 ft. on the start. The concrete was mixed very wet, 1 part cement, 3 parts sand and 7 parts stone; no plastering or water-proofing of any kind was used, but the tank was found to be absolutely water-tight, although the mixture used has not generally been considered or found impermeable.

Piers and Abutments.—Concrete is now so extensively used in all parts of the United States for the foundations, piers and abutments of bridges, that it will be unnecessary to mention particular examples. It will be of interest, however, to note one case,† which, so far as the writer knows, has no parallel. Five piers on North Platte River, Wyoming, Union Pacific Railroad, were built at —30 fahr. with hot concrete. In setting, it was found that the south ends of the piers had moved west from $\frac{3}{8}$ to $1\frac{1}{4}$ in., and had also settled from $\frac{1}{4}$ to $\frac{3}{8}$ in. more than the north ends.

Concrete piers for steel bridges are not usually reinforced with steel, but six concrete piers, reinforced with steel bars, are now under construction for a plate-girder bridge over the Cuivre River, on the Chicago, Burlington and Quincy Railroad, and old railroad rails have been used for pier reinforcements on other railroads.

Sewers.—Concrete-steel sewers are rapidly superseding brick or concrete sewers, and are being constructed in a great variety of shapes and capacities. Extensive sewer systems of concrete-steel have recently been constructed, or are now under construction, in New Orleans, La.; Cleveland, Ohio; Boston, Mass.; Wilmington, Del., and nearly all the cities of the United States.

Floors.—Concrete-steel construction is now extensively used for the floors and roofs of warehouses, office buildings, banks, stores, etc., and is the most perfect fire-proof construction known. A great

* *Transactions*, Am. Soc. C. E., Vol. L, p. 454.
† *Engineering News*, Vol. XLVII, p. 372.

variety of patented systems have been used. Twenty have been approved by the Bureau of Buildings, and are in use in the City of New York, and still other systems are used in Western cities; this applies to work built in place. Other systems are used in which the parts are moulded and allowed to harden for any desired length of time before being set in position in the structure. De Mann floor blocks consist of I-beams, reinforced in web and flanges, which are slid between the flanges of the supporting steel I-beams, the bottom flanges of the blocks forming the ceiling and the top flanges the floor. The Visintini system consists essentially of concrete girders of the Pratt, or Warren, type, in which frameworks of steel bars are embedded. This system was invented by Mr. Franz Visintini, of Zurich, and has been patented in Europe and the United States. It is being used to quite a large extent in Europe, and is now being introduced and is controlled in the United States by the Concrete Steel Engineering Company of New York. This system is well adapted to girders, beams and floors of long span, roofs, stairways, etc., and is claimed to give a maximum of efficiency with a minimum of material, weight and cost. Thacher floor units are designed for the floors of bridges or buildings. They consist essentially of inverted trough sections of concrete, reinforced with steel bars. The effective length of span is materially reduced, and the units can be placed in position after the supporting steel beams are in place.

None of the three systems last mentioned require centering. Mr. Hennebique speaks of many tests made by the Orleans Railroad in France, which demonstrated that, all proportions being equal, powerful shocks produced an effect thirty times stronger on iron floors than on concrete-steel floors.

Girders and Columns.—Concrete-steel girders are practicable, and often economical, up to spans of considerable length. The longest span designed by the writer, which has been constructed, is 40 ft., but spans of 52 ft. were used for the roof of the Central Felt and Paper Company's concrete-steel factory building at Long Island City, N. Y., and Mr. Cummings has under construction at Pittsburg, Pa., a machine-shop of concrete-steel construction throughout, the roof having a clear span of 54 ft.

Concrete-steel columns for fire-proof buildings and other purposes are gaining in favor, and are now quite largely used.

Piles.—Concrete and concrete-steel piles have not yet been used to a large extent in the United States. Simplex concrete piles were used for the foundations of the new Post-Office at Lawrence, Mass., and for the foundations of several buildings at Washington Barracks, D. C. They are made by driving into the ground to the proper depth a metal pipe with a detachable point of concrete or cast iron, then slowly withdrawing the pipe as the concrete is rammed into the hole. Concrete-steel piles were used for the foundations of a large train-shed in Atlanta, Ga., which, so far as the writer knows, is the only example of such use in the United States. The writer understands that this was not completely successful, due, probably, to the piles being cast in a horizontal position, and driven with a comparatively light hammer, whereas in Europe, where complete success has been achieved, it is considered essential to cast the piles in a vertical position, and to drive them with a heavy hammer, the weight of which is not less than that of the heaviest pile, with a drop of from 3 to 6 ft. The Hennebique and other designs of concrete-steel piles have been used to quite a large extent in Great Britain and Europe for foundations, wharves, quay walls, etc., and there cannot be found anywhere a more promising field for the extensive use of concrete-steel piles than in the teredo-infested waters of the United States.

Concrete Bridges.—Quite a number of concrete bridges have been built, or are now under construction, in the United States. The oldest bridge of this character, of which the writer has any record, was built by John C. Goodridge, in 1871, in Prospect Park, Brooklyn, N. Y., and is known as the Cleftridge Bridge. A concrete arch, 31-ft. span and 5-ft. rise, was erected in the Cemetery of the Evergreens, in East New York, in 1872. The Erie Railway Tunnel at Bergen, N. J., was lined with concrete in 1874. The arch has a span of 28 ft. A concrete-arch bridge of 40-ft. span was built by A. Geisal, of St. Louis, Mo., at Belleville, Ill., in 1895. No important concrete bridges were built in the United States until 1901. In 1902 a bridge was built at Mechanicsville, N. Y., consisting of two spans of 100 ft. each and one span of 50 ft., rise of arches, 20 ft. In 1902-03 a bridge was built over the Santa Ana River, near Riverside, Cal., containing eight spans of about 86 ft. each, rise of arches,

36.9 ft.; also the Pecos Valley Aqueduct, New Mexico, containing four spans of 100 ft. each, rise of arches, 25 ft. It carries a flume, 20 ft. wide and 18 ft. high, the walls of which are concrete, 2 ft. thick, reinforced horizontally and vertically with T-rails.

In 1903 the Delaware, Lackawanna and Western Railroad built twelve spans of 37.2 ft. each as part of their extensive improvements at Newark, N. J., and the Illinois Central Railroad erected over the Big Muddy River, near Carbondale, Ill., three spans of 140 ft. each, rise of arches, 30 ft. The approaches to the bridge over the Mississippi River at Thebes, Ill., contain twelve full-centered arches, six spans of 65 ft. each and one span of 100 ft. in the Missouri approach, and five spans of 65 ft. each in the Illinois approach.

The Connecticut Avenue Bridge at Washington, D. C., will contain five spans of 150 ft. each and two spans of 82 ft. each, full-centered concrete arches. This work was started some years ago and suspended for want of money, but Congress has now made the necessary appropriation, and work will be resumed. This bridge will contain the largest spans of concrete arches in America. Larger spans have been built in Europe. The bridge over the Danube, at Munderkingen, Germany, built in 1893, having a clear span of 164 ft., and a bridge now under construction at Munich, will have two clear spans of 328.1 ft. each. The concrete arches built in Europe and the United States, however, have one important difference: Those in Europe and Great Britain are all three-hinged arches, and those in the United States are all fixed arches. Time may demonstrate which is the better practice.

Concrete-Steel Bridges.—On April 4th, 1894, Mr. Fr. von Emperger read a paper* before the American Society of Civil Engineers, in which the subject was brought prominently before American engineers. This has done more than any other one thing to promote the construction of concrete-steel bridges in the United States. Previous to this time no concrete-steel bridges of any importance had been built in the United States. Two spans of 25 ft. 4⅜ in. each, with rise of 6 ft. 6 in., were built over Pennypack Creek, Pine Road, Philadelphia, Pa., in 1893. The arches had a thickness of 27 in. at the crown, and the spandrel filling was of rammed concrete. In addition to this, 1½-in. mesh-wire nets were

* "The Development and Recent Improvement of Concrete-Iron Highway Bridges," *Transactions*, Am. Soc. C. E., Vol. XXXI. p. 438.

distributed horizontally and vertically through the concrete. The object evidently being to bind the concrete together rather than to assist it in sustaining stresses.

The inventor of the first concrete-metal arch ever built is generally conceded to be Jean Monier, of Paris, France. He embedded wire nets in concrete, or, rather, mortar. The genuine Monier system had only one wire netting near the intrados of the arch, but engineers soon learned that this was not sufficient, and later two nettings were used, one near the intrados and the other near the extrados. Many Monier arches have been built in Europe, and tests made on them by the Austrian Society of Engineers and Architects show their superiority over concrete alone, but they have some serious disadvantages. The transverse wires of the nets take no stress and add greatly to the cost, with very little corresponding benefit. The nets are also very flexible and difficult to manage, and the close mesh interferes seriously with the placing of the concrete, so that no coarse aggregates, like gravel and broken stone, could be used, adding greatly to the cost of the concrete. Notwithstanding these disadvantages, some quite notable Monier arches have been built. The writer has not kept track of what has been done in Europe during the past few years, but Mr. von Emperger mentions in his paper, previously referred to, that three spans of 128 ft. each and 11-ft. rise, were built in Switzerland in 1891, in which the thickness of arches was $6\frac{3}{4}$ in. at the crown and 10 in. at the spring, and that one 132-ft. span, 14.66-ft. rise, was built in Germany in 1890, in which the arch has a thickness of 9.88 in. at the crown. Such delicate dimensions would not be seriously entertained in the United States. The Melan system was invented by Joseph Melan, of Austria-Hungary, in 1892, and patented in the United States in 1893. It consists of a concrete arch in which iron or steel beams are embedded. For small spans the beams are usually rolled I-beams, and for spans of considerable length they usually consist of four angles latticed.

A Committee of the Austrian Society of Engineers and Architects made a large number of tests on brick, concrete, concrete-steel and other arches, from 4.43 to 74.5 ft. span, a report of which was published in 1895. The Melan arch is a direct outcome of these tests and their results. The report states:

"From the behavior of this construction there is no doubt that these vaults have a far superior carrying capacity than either the plain concrete or the Monier arch," etc.

The first Melan arch bridge built in the United States was in 1894, at Rock Rapids, Iowa. It has a clear span of 30 ft. and a rise of 6 ft. 6 in. Since that date the Concrete Steel Engineering Company, of New York City, and their predecessors have built, or are now building, under the Melan, Thacher and von Emperger patents, about three hundred spans of concrete-steel bridges, distributed over nearly all parts of the United States. Among the more important of these bridges, now completed, are the following:

The Kansas River Bridge, at Topeka, Kans., five spans, total length 693.0 ft., width 39.0 ft.

The Passaic River Bridge, at West Street, Paterson, N. J., three spans, total length 282.5 ft., width 50.0 ft.

The two bridges over Fall Creek, at Illinois Street and Meridian Street, Indianapolis, Ind., each containing three spans, and having a total length of 278.0 ft. The width of the bridge at Illinois Street is 60 ft. and at Meridian Street, 70 ft.

The Miami River Bridge, at Main Street, Dayton, Ohio, seven spans, total length 668.0 ft., width 56.0 ft.

The Des Moines River Bridge, at Sixth Street, Des Moines, Iowa, three spans, total length 370.0 ft., width 42 ft. 4 in.

The Muskingum and Licking River V-Bridge, at Zanesville, Ohio, two arms of three spans each and one arm of two spans, total length about 1 020.0 ft., width 43.0 ft. This bridge was designed by E. J. Lander, M. Am. Soc. C. E.

The bridge over Cedar River, at Waterloo, Iowa, seven spans, total length 586.0 ft., width 56.0 ft.

The bridge over the St. Joseph River, at Mishawaka, Ind., three spans, total length 502.0 ft., width 40.0 ft.

The bridge over Grand River, at Grand Rapids, Mich., five spans, total length 494.0 ft., width 63 ft. 10 in. This bridge was designed by L. W. Anderson, City Engineer.

The Utica and Mohawk Valley Railroad Viaduct, at Herkimer, N.Y., ten spans, total length 764.0 ft., double track. This bridge was designed by the Osborn Engineering Company.

The two bridges across the rapids of Niagara River a short distance above the Falls, the one from the main land to Green Island has three spans, total length 412.0 ft., width 40.0 ft., and the one from Green Island to Goat Island has three spans, total length 198.0 ft., width 40.0 ft. These bridges were designed by R. S. Buck, M. Am. Soc. C. E., and are particularly notable on account of their locality.

The bridge across the Jucaguas River in Porto Rico, three spans, total length 404.0 ft., width 20.0 ft.

Among the more important bridges now under construction are the following:

The bridge over the tracks of the Atlantic Coast Line, Seaboard Air Line, and Florida East Coast Line, at Jacksonville, Fla., eleven spans, total length 845.0 ft., width 58.0 ft.

The Miami River Bridge, at Third Street, Dayton, Ohio, seven spans, total length 798.0 ft., width 64 ft. 2 in.

The Kankakee River Bridge, at Washington Avenue, Kankakee, Ill., seven spans, total length 593.0 ft., width 46.0 ft.

The St. Joseph River Bridge, at South Bend, Ind., four spans, total length 542.0 ft., width 72.0 ft.

The Tuscarawas River Bridge, at Canal Dover, Ohio, four spans, total length 528 ft. 6 in., width 45.0 ft.

The Tuscarawas River Bridge, at Goshen, Ohio, four spans, total length 416 ft. 6 in., width 16 ft. 6 in.

The Naugatuck River Bridge, at Derby, Conn., three spans, total length 284 ft., width 54 ft.

The Pelham Bay Park Bridge, New York City, six spans, total length 880 ft., width 52.0 ft.

Two bridges across White River, in Indianapolis, Ind., one at Morris Street, and the other at Michigan Street. Morris Street Bridge has five spans, total length 622 ft., width 52.5 ft. Michigan Street Bridge has three spans, total length 464 ft., width 63 ft. The Fall Creek Bridge at Fair Grounds, Indianapolis, Ind., three spans, total length 278 ft., width 25 ft. These bridges were designed by H. W. Klausmann, County Surveyor.

All these bridges have three or more spans.

The great majority of concrete-steel bridges, thus far built, have one span only. A few of the most notable of these are as follows:

A bridge at Lansing, Mich., clear span 120 ft., length over all 170 ft., width 54 ft.

A bridge in Yellowstone Park, clear span 120 ft., length over all 160 ft., width 17 ft. 6 in. This bridge was designed by H. M. Chittenden, M. Am. Soc. C. E., Major, Corps of Engineers, U. S. A.

A bridge now under construction at Sanderson Avenue, Scranton, Pa., clear span 110 ft., length over all 162 ft., width 45 ft. 2 in.

A bridge now under construction in Branch Brook Park, Newark, N. J., clear span 132 ft., length over all 225 ft., width 73 ft. 7 in. This will be the longest span of concrete-steel bridge in the United States.

The writer can see no good reason why concrete-steel bridges with spans of 500 ft., or more, cannot be built with perfect safety and often with economy; he has designed and submitted bids on spans as great as 300 ft., and although the plans and prices were satisfactory, other and weightier considerations, from the point of view taken by the officials, induced them to prefer steel structures. It is unfortunate from an engineering standpoint that very few bridge sites are located so as to make long spans economical, or even possible, and in most cases, to meet the conditions of grade and high water, it is necessary to have comparatively short spans with minimum rise of arches. A considerable contraction of waterway by piers, or approaches, is not such a serious matter as many imagine, as the water between the obstructions will about make up in velocity what it lacks in area. At Topeka, Kans., the waterway was contracted from 850 to 540 ft., or 36.5%, with no serious consequences until the unprecedented high water of 1903, when about 160 ft. of earth-fill on the north end went out, because the grade was so low that the water overflowed the bank and washed it out, but the water kept on rising notwithstanding, and reached its maximum stage after the embankment disappeared.

Concrete-steel bridges are rapidly gaining in favor. They cost more than light iron bridges with plank floors, but in many localities they will cost no more, and frequently less, than good steel bridges

carrying a pavement. The advantages of a concrete-steel bridge as compared with a concrete bridge are not due so much to diminished sections or cost as to the greatly increased security which the steel affords in providing against settlements or other conditions which cannot be calculated or foreseen. Under normal conditions the steel is not strained to much more than one-quarter of its elastic limit, so that a very large reserved force is always available for emergencies. The claimed and generally recognized advantages of a concrete-steel bridge, as compared with a steel bridge, are as follows: They make handsomer structures, and architectural ornamentation can be applied to any extent desired; if properly designed and constructed, they have vastly greater durability and greater ultimate economy; they are comparatively free from vibration and noise; they are proof against tornadoes and fire, and also against floods, if the foundations are protected from scour; the cost of maintenance is confined to the pavements; home labor and home material are utilized to a much greater extent in building them, so that the greater part of the money which they cost is left among the people who pay for them.

Fire-Protection.—It has been quite well established by several large fires, as well as by comparative tests, that concrete and concrete-steel are superior to hollow tile for resisting intense heat.

Comparative tests* of a hollow, hard, tile arch and a Roebling concrete arch, made November 19th, 1897, in New York City, resulted in the collapse of the tile arch in 3 hr. 16 min. after the fire was started and when 2 300° fahr. had been reached. The concrete arch was not damaged.

A fire in Pittsburg, Pa., May 3d, 1897, destroyed Horne and Company's store having fire-proofing of hard clay tile, and the Horne office building with fire-proofing of porous terra cotta, but the concrete-steel floor arches of the Methodist Book Building were denuded of plaster, otherwise only slightly damaged.†

A fire, April 11th, 1902, in the concrete-steel factory of the Pacific Coast Borax Company, of Bayonne, N. J., destroyed a large amount of machinery, and all of the exposed metal and wood used in the construction, or stored in the building, and the heat was

* *Engineering News*, Vol. XXXVIII, p. 367.
† *Engineering News*, Vol. XXXVII, p. 316.

sufficient to fuse copper, but the concrete-steel walls and floors were practically uninjured.

The fire-proof buildings in the path of the great Baltimore fire of February 7th and 8th, 1904, stood very well, but, according to the reports of most of the experts who have examined them, the concrete construction was much superior to hollow tiles. *Engineering News** requested several experts to prepare reports on the effects of this fire on structural materials. The following conclusions were reached: S. C. Weiskopf, M. Am. Soc. C. E., New York City, did not make careful examination—expects to do so later; H. de B. Parsons, M. Am. Soc. C. E., New York City, concludes, after thorough examination, that monolithic concrete is superior to hollow-tile floors; Carl F. Grieshaber, New York City, speaks highly of the behavior of reinforced concrete; he found terra cotta side construction superior to end-to-end construction. His conclusions are: Concrete construction acted best, side construction terra cotta next best, and end-to-end terra cotta construction poorest, also, that terra cotta deteriorated under fire while concrete did not.

A. L. A. Himmelwright, M. Am. Soc. C. E., New York City, says there is no doubt that concrete made from steam-boiler cinders and Portland cement made the best showing. Howard Constable, M. Am. Soc. C. E., New York City, says terra cotta and concrete have given a very good account of themselves.

Protection of Steel in Concrete.—Will concrete protect from oxidation iron or steel embedded therein? This is an important question, for, if not, concrete-steel construction will deteriorate, and in time fail, and as all engineers at least are not fully satisfied on this subject, such testimony as the writer has been able to collect will be of interest.

Spencer B. Newberry, Assoc. M. Am. Soc. C. E., mentions a concrete-steel water main† on the Monier system, at Grenoble, France, 12 in. diameter, $1\frac{6}{10}$ in. thick, containing steel framework of $\frac{1}{4}$ and $\frac{1}{16}$-in. steel rods, taken up after fifteen years' use in damp ground. The adhesion was found perfect and the metal absolutely free from rust. He also mentions a concrete-metal retaining wall in Berlin which

* *Engineering News*, February 25th and March 3d, 1904.

† *Engineering News*, Vol. XLVII, p. 335.

was examined after eleven years' use and the metal found free from corrosion, except in some cases where the rods were within 0.3 or 0.4 in. from the surface. Professor Newberry explains how the effect of concrete in preserving metal is not due to the exclusion of air, and even though the concrete be porous and not in contact with the metal at all points, it will still filter out and neutralize the carbonic acid and prevent corrosion.

G. Bouscaren, M. Am. Soc. C. E., removed, in 1875, several links* from the anchorage of a suspension bridge partly built by Roebling in 1855, and they were found to be in a perfect state of preservation.

L. L. Buck, M. Am. Soc. C. E., states that he found rust on the anchorage of the Niagara Suspension Bridge where limestone was in contact with the metal, but where limestone was not in contact, and no movement had taken place, the metal was found in perfect condition after twenty-five years.

E. L. Ransome, Assoc. Am. Soc. C. E., saw, in Chicago, Ill., workmen breaking up slabs of limestone concrete which had covered sidewalk vaults for eight or ten years. The slabs had iron rods embedded which were rust free.

William Sooy Smith, M. Am. Soc. C. E., speaks of a small piece of iron set in mortar taken from the base of the obelisk in Central Park, New York City, which was bright after 2 300 years; he also says that in removing a bed of concrete at a lighthouse in the Straits of Mackinac, twenty years after it was laid, and 10 ft. below water surface, embedded iron drift-bolts were found free from rust.

Albert A. Trocon, M. Am. Soc. C. E., speaks of a bridge over the Osage River, Missouri, built on iron cylinder piers† filled with Louisville cement limestone concrete, which was wrecked by high water after seven years' service. The center pier was overturned, leaving the bottoms of the cylinders, after the water subsided, in plain view. The concrete was removed from these cylinders for a depth of 8 or 10 ft., and the iron was found absolutely free from rust.

Professor Charles L. Norton made a large number of experiments with concrete bricks,‡ 3 by 3 by 8 in., in which steel rods, sheet steel

* *The Engineering Record*, Vol. XXXVIII, p. 253.

† *The Engineering Record*, Vol. XXXVIII, p. 273.

‡ Report No. 3, Insurance Engineering Experiment Station, Boston, Mass.

and expanded metal were embedded. The specimens were enclosed in tin boxes with unprotected steel, and exposed for three weeks. One portion was exposed to steam, air and carbon dioxide, another to air and steam, another to air and carbon dioxide, and another was left on the table in the testing-room. His conclusions were as follows:

First.—Neat cement is a perfect protection.

Second.—Concrete should be dense without voids or cracks, and be mixed wet.

Third.—The corrosion found in cinder concrete is mainly due to iron oxide in the cinders and not to the sulphur.

Fourth.—Cinder concrete, if free from voids and well rammed, is about as effective as stone concrete.

Fifth.—It is important that the steel be clear when embedded in concrete.

Sixth.—It is essential that the steel be coated with cement before embedding in concrete.

The unprotected pieces of steel were found to consist of more rust than steel.

M. Breuillié, a French engineer, made some interesting and valuable experiments on concrete-steel slabs* subjected to high-water pressure. The slabs were 36 by 39 by 11.8 in., with steel rods and wires embedded at different depths in the slabs. The slabs were subjected for six days to intermittent water pressure of from 39.4 to 50.0 ft. The water penetrated every part of the slabs. The slabs were then left in the open air, and the condition of the metal tested from time to time and always found in perfect condition. He observed that the metal was dull after contact with the concrete; that adhesion was destroyed where the water had penetrated; that bars, having a slight layer of rust when embedded, were free from rust in 15 or 20 days; that water after passing through the slabs contained less mortar salts than before; that under pressure of 50 ft. adhesion was destroyed but bars did not rust. He concludes that a salt is formed by the action of the cement on iron, which is dissolved by water.

Professor Norton gives the result of further tests on the protection of steel embedded in concrete.† Specimens of steel, clean

* *The Engineering Record*, Vol. XLVI, p. 280.

† Report No. 9, Insurance Engineering Experiment Station, Boston, Mass.

and in all stages of corrosion, were embedded in stone and cinder concrete, wet and dry mixtures, and exposed to moisture, carbon dioxide and sulphurous gases. Some were treated in tanks supplied intermittently with steam, hot water, moist air, dry air, and continuously with carbon dioxide for from one to three months. Under the conditions followed, unprotected steel vanished into streaks of rust, but protected by an inch or more of sound concrete, the steel was absolutely unchanged, and he concludes that steel embedded in concrete, mixed wet and well, whether stone or cinder concrete, will be perfectly protected for all time.

Mr. Ransome mentions that in tearing up some sidewalk in Bowling Green Park, New York City, which had been in use twenty years, some embedded steel rods were found to be in perfect condition.* The Turner Construction Company exposed concrete blocks, in which steel bars were embedded, on the beach at low tide where they were covered by salt water, except for 3 or 4 hours each day, and after 9 months' exposure the blocks were broken, and the bars found free from rust. Other examples could be given, but the writer considers the above sufficient to establish clearly that concrete is a perfect protection for embedded steel.

Cement Paint.—Cement paint is said to be largely used by the railway companies of France, to protect the metal work of bridges from rust and locomotive gases.† The metal is brushed and dampened and given two coats of liquid cement and sand. It was used for protecting the steel beams of the Boston Subway, and is used largely in European distilleries for painting iron spirit tanks, the adhesion being increased by allowing the metal to rust somewhat before applying the paint. The writer knows of some cases in the United States where cement paint was used without success, as it failed to adhere to the entire surface, and if there is any sure way of making it do so the writer hopes the discussion will bring it out, for if satisfactory adhesion of cement can be secured, either with or without sand, it will undoubtedly prove to be the best paint and the most perfect protection for exposed steelwork known. For protecting steel bars buried in earth, the writer has wrapped them with canvas soaked in thick Portland cement grout with a heavy coating of grout over the canvas, and believes it will be permanently effective.

* *The Engineering Record*, Vol. XLIX, p. 532.
† *Cement*, Vol. III, 1902.

Finish.—The greatest objection to the use of concrete for the exposed surfaces of structures in which beauty is an important consideration is the difficulty of producing a satisfactory finish. Concrete, as it usually comes from the moulds showing the joints, knots and grain in the casing, has more the appearance of a piece of rough carpenter work than of finished masonry, and some special treatment is necessary. Concrete is faced frequently with masonry, brick or tile, but this dodges the case without meeting it. Plastering is resorted to frequently, but not always with success. E. Duryee mentions some examples which gave good results.* The portals of two tunnels in Los Angeles, Cal., were plastered with two coats of 1 cement, 4 sand and 1 lime paste; where finished rough it did not show hair-cracks, but when finished smooth it did show them. The concrete pedestals of Kaskaskie Viaduct, Chicago and Eastern Illinois Railway, are plastered with 1 cement, 1 sand, and are in first-class condition. The piers of the Arkansas River Bridge, Kansas City Southern Railroad, were plastered with three coats, the first two, 1 cement, 3 sand, and the third, 1 cement, 1 sand, and are in good condition. Mr. Duryee considers a mixture of 1 cement, 3 sand, 1 lime paste the safest and best, and that excessive troweling should be avoided, and the plastering kept damp for two weeks. A concrete bridge at Aconomowoc, Wis., built by Stamsen and Blome of Chicago, Ill., had a mortar face composed of 1 part cement, 1 part granite screenings and 1 part torpedo sand. On the second day after completion the moulds were removed and the surface rubbed with a soft stone and water. The Inman arch Hohenzollern had a facing of 1 part cement and 5 parts broken limestone. After setting twelve hours the loose cement was removed by water and brushes.

About the same process was followed by H. H. Quimby, M. Am. Soc. C. E., for a bridge in Philadelphia, Pa. The walls of the Pacific Borax Company's factory at Bayonne, N. J., are finished to represent coursed ashlar work by inserting wooden strips in the moulds, and dressing the faces with a pneumatic hammer. One man was able to dress from 300 to 600 sq. ft. in 10 hours, or from 100 to 200 sq. ft. by hand. Many of Mr. Ransome's buildings are finished in this way, and the effect is good. A very good finish

* *Cement*, Vol. II, 1901.

can be produced by using smooth moulds, and depositing wet concrete directly against them; then, after removing the moulds, floating the surface with a wooden float, using only sufficient mortar to fill the pores, and to give a smooth finish. Mr. Cummings has produced a good finish by going over the surface with a wire brush while the cement was still green.

B. E. Turnbull, Chief Inspector of the ten-span, concrete-steel viaduct for the Utica and Mohawk Valley Railway at Herkimer, N. Y., produced a very superior finish in the following manner: For a hard wall, the surface was wet and a thin 1 : 2 mortar was applied with a brush. The surface was then thoroughly rubbed with a piece of grindstone or carborundum, removing all board marks and filling all pores, producing a lather on the surface of the concrete, and before this had time to dry it was gone over with a brush dipped in water, producing a smooth finish and uniform color. For a green wall, when the moulds were removed in less than seven days, the surface was wet and a thin grout of pure cement was applied with a brush, the surface was then rubbed with a piece of grindstone or carborundum and finished in the same manner as previously stated. The same process is being used for the eleven-span, concrete-steel viaduct over the tracks of the Atlantic Coast Line, Seaboard Air Line and Florida East Coast Line at Jacksonville, Fla., and the results are exceedingly satisfactory.

George W. Lee, Jun. Am. Soc. C. E., describes the method used by the New York Central Railroad for giving a good finish to exposed concrete surfaces.* The forms of 2-in. tongued and grooved pine were coated with soft soap, all openings in the joints of the forms being filled with hard soap. The concrete was then deposited, and as it progressed was drawn back from the face with a square-pointed shovel, and 1:2 mortar poured in along the forms. When the forms were removed, and while the concrete was green, the surface was rubbed with a circular motion with pieces of white fire-brick, or bricks composed of 1 part cement and 1 part sand; the surface was then dampened and painted with 1:1 grout rubbed in, and finished with a wooden float, leaving a smooth and hard surface when dry.

Impermeable Concrete.—Impermeable concrete, or concrete made

* *Engineering News*, Vol. XLIX, p. 246.

impermeable by some kind of water-proof coating, is frequently required, either for inclosing a space which must be kept dry, or for storing water or other liquids, and quite a number of valuable experiments have been made for the purpose of discovering the most effective way to accomplish this result.

In 1902, Mr. J. B. McIntyre and A. L. True, Jun. Am. Soc. C. E., of the Thayer School of Civil Engineering, made 97 experiments* to determine if possible a concrete which would be impermeable to water under high pressures. The specimens were 10 in. in diameter and 9 in. high, with ¾-in. pipe inserted to a depth of 4 in. The specimens were subjected to a pressure of 20, 40 and 80 lb. per sq. in. for 2 hours. All specimens containing from 30 to 45% of 1:1 mortar were impermeable, some of the specimens containing from 40 to 45% of 1:2 mortar, and some specimens of 1:2:4 and 1:2½:4 were also impermeable under a pressure of 80 lb. per sq. in., equivalent to a head of 184 ft. They recommend 1:2:4 or 1:2½:4 concrete for moderate pressures.

At the annual convention of the American Society of Civil Engineers, in June, 1903, there was an informal discussion on impervious concrete which brought out some valuable matter. R. W. Lesley, Assoc. Am. Soc. C. E., quotes the conclusions of M. R. Feret, a noted expert of the French Government, as the result of a large number of experiments extending over a period of five years. He found that permeability diminished as the proportions of cement increased, also diminished rapidly with time, that the concrete should be mixed wet, and is least permeable when the proportion of medium-sized grains is small and the coarse and fine grains are about equal to each other.

From experiments made by Italian engineers at Genoa, Italy, it was found that a mixture of 1:3.5:4.5 was impermeable under a head of 13 ft., and barely permeable under a head of 27 ft., and that a mixture of 1.0:2.2:2.7 was impermeable under a head of 40 ft.

It is generally considered that a monolithic construction, a wet mixture, a rich concrete and an aggregate proportioned for great density are essential for impermeability.

Mr. William B. Fuller thinks that extra insurance of imper-

* *Engineering News*, Vol. XLVII, p. 517.

meability can be secured by reversing the ordinary process of machine mixing, introducing the water first, then the cement to form grout, then the sand, and lastly, the stone or gravel.

Professor Baker gives the following formula for making mortar impervious: 1% by weight of powdered alum is added to the dry cement and sand, and 1% of potash soap (ordinary soft soap is good) is dissolved in the water used in mixing. W. K. Hatt, Assoc. M. Am. Soc. C. E., has used with success a 5% solution of alum and water, and a 7% solution of soap and water, these solutions being used in equal parts in mixing the mortar or concrete.

Various coatings have been used to render concrete water-tight. For cistern work two coats of Portland cement grout have been found sufficient. About 1 in. of rich Portland cement mortar has usually been found effective under high pressure. A coating of asphalt alone, or asphalt with tarred or asbestos felt laid in alternate layers between layers of concrete, has often been used with success. Coal-tar pitch and tarred felt in alternate layers have been used extensively and successfully in New York City for water-proofing. Captain William C. Langfitt, Corps of Engineers, U. S. A., has used successfully a water-proofing wash composed of one pint of an alum and lye solution mixed with 10 lb. of cement, thinning with water until the mixture spreads easily with a brush. It should be applied while the concrete is green and until it lathers freely. The solution consists of 1 lb. of concentrated lye, 5 lb. of alum, and 2 gal. of water. Eugene W. Van C. Lucas, M. Am. Soc. C. E., Captain, Corps of Engineers, U. S. A., used boiled linseed oil with success, coating the surface until the oil ceased to be absorbed.

Stone Dust vs. Sand.—A large number of tests have been made on mortars and concretes in which stone dust and sand have been used in direct comparison, and there can be no doubt that stone dust is much superior to any sand. Harry Taylor, M. Am. Soc. C. E., Captain, Corps of Engineers, U. S. A., tested 1 650 briquettes of 1:3, 1:4 and 1:5 mortars, at 1, 3, 6 and 12 months, using standard crushed quartz, Plum Island sand and crusher dust. The briquettes with crusher dust had a mean strength 72% greater than with crushed quartz, and 2.3 times greater than with Plum Island sand

A 1:5 mixture with stone dust was stronger than a 1:3 mixture with crushed quartz.

Mr. G. J. Griesenauer, Chicago, Milwaukee and St. Paul Railroad, made 225 tests* of briquettes in which limestone screenings were used in comparison with Hammond pit sand, which was the best that could be obtained. Sized limestone screenings (between No. 12 and No. 40 sieve) averaged 74% better than Hammond sand, and screenings not sized averaged 115% better than Hammond sand, and a mortar of 1:6 screenings was 23% stronger than a mortar of 1:3 sand. Gravel screenings were not found much superior to sand. A report on the highways of Maryland gives the result of tests in which stone screenings and Potomac River sand were compared. The briquettes made with screenings were from 34 to 62% stronger than those made with sand. Tests made by the Board of Public Works of Porto Rico in 1901, show stone dust to be much superior to standard sand, and transverse tests made by the Boston Transit Commission† show stone dust to be much superior to Plum Island sand.

Wet or Dry Mixtures.—Until within the past few years the majority of engineers in the United States preferred and used a dry mixture of concrete, but now this has been superseded almost completely by a medium, or very wet mixture, often so wet as to require no ramming whatever. Mr. A. S. Cooper, Government Engineer, as long ago as 1895, called attention to the advantages of a wet mixture. He found by experiment that dry mortars give the best results in short-time tests, and wet mortars in long-time tests. Alfred Noble, Past-President, Am. Soc. C. E., and George W. Rafter, M. Am. Soc. C. E., have also made a large number of tests of briquettes with dry, medium and excess mortars, and, although the dry mortars gave slightly the best results for these small specimens, prefer the wetter mixture for actual work. H. W. Parkhurst, M. Am. Soc. C. E., made some valuable experiments‡ on medium, dry and wet mixtures, and found the medium mixture most dense, wet next and dry least, and concludes that the medium mixture is the most desirable, one that will not quake in handling,

* *Engineering News*, Vol. XLIX, p. 342.
† Eighth Annual Report, Boston Transit Commission, 1902.
‡ *Journal*, Western Society of Engineers, June, 1902.

but will quake under heavy ramming. He found medium 1% denser than wet, and 9% denser than dry concrete, he considers thorough ramming important. The writer has seen concrete put in so wet that it would not only quake but flow freely, and after setting it appeared to be very dense and hard, still he thinks the present tendency is for too much, rather than for too little water, and that thorough ramming is desirable.

Impurities in Aggregates.—It has been known for some years that quite a large percentage of clay in sand or gravel had no bad effect on mortars and concrete, but loam was considered fatal, and the writer has had some experience which seemed to justify such a conclusion; but quite recently some tests* have been made by J. C. Hain, Assoc. M. Am. Soc. C. E., Chicago, Milwaukee and St. Paul Railroad, which seem to show that sand containing loam is equal to or superior to clean sand. Tests were made on 1:2 and 1:3 mortar, comparing clean sand with sand containing 2, 5, 10 and 20% of loam (rich surface soil). For the 1:2 mortar, clean sand gave slightly better and more uniform results, but for the 1:3 mortar, sand containing up to 20% of loam by weight gave as high average results as clean sand, though the latter gave much more uniform results. Tests were also made with sand from different pits and containing from 2.5 to 7.7% of loam and clay, and those containing the highest percentage of impurities give the best results. Tests made by the Board of Public Works of Porto Rico on briquettes of 1:2 mortar give 25% better results with washed than with unwashed sand. Before accepting sand containing a large percentage of foreign matter, the writer believes that thorough tests should be made of that particular sand, washed and unwashed.

Retempering.—Many engineers believe retempering to be injurious to Portland cement concrete, and forbid it in their specifications, but many tests have been made that show this to be a benefit rather than otherwise. Tests† made by Thomas S. Clark, Resident Engineer, Manhattan Power Station, New York City, on 1:3 Rosendale and Portland mortars retempered after 1 hour, and tested at age of 28, 56 and 112 days, show that the Rosendale mortars

* *Engineering News*, Vol. LI, p. 413.

† *Engineering News*, Vol. XLVIII, p. 67.

lost an average of 35% in strength by retempering, and that the Portland cement mortars gained an average of 8% in strength by retempering. Mr. G. T. Skeels, Assistant City Engineer, Sioux City, Iowa, made tests* on 50 briquettes of 1:2 Portland cement mortar, which were continuously mixed for from 15 min. to 8 hr. 55 min., water being added from time to time, and tested after 15 days. The briquettes that gave the highest test were from mortar which had been continuously mixed for 4 hr. 55 min., being 31% stronger than the specimens from mortar mixed 15 min.; specimens from mortar mixed for 8 hr. 55 min. were 24% weaker than those from mortar mixed 15 min.

Delay in Placing.—The Kinipple system of laying concrete under water† consists in allowing concrete to set partly, so that when thrown into foundations the cement will not separate, but the concrete is soft enough to form a compact structure. He found it equal in every respect to concrete deposited in air, and found by experiment that 1:3½ concrete does not lose strength by delay of 8 hours in placing, and if rammed into moulds will form a monolithic mass. A 1:3½ mixture was left 3 hours to set, and a 1:6 mixture, 5 hours before being deposited. The best results were obtained when the concrete was mixed with a minimum of water and rammed into boxes, and deposited when it had the solidity of stiff clay; he has deposited concrete in this manner through from 50 to 70 ft. of water with complete success.

Mr. Ransome says he has experimented with several brands of Portland cement, and found that they were invariably improved in tensile strength by a delay of from 1 to 4 hours between mixing and placing.

Freezing.—Walter A. Rogers, M. Am. Soc. C. E., of the Chicago, Milwaukee and St. Paul Railroad, made some interesting tests‡ on 12-in. cubes of Portland cement concrete 1:3:4, exposed to freezing weather. The capacity of the testing machine was only 185 000 lb., and it is unfortunate that the cubes were not of smaller size, or a more powerful machine used, but the results are of some value. Two cubes left in office, and tested after 28 days, stood over 185 000

* *Engineering News*, Vol. XLVIII, p. 382.
† "Notes on Concrete" by John Newman, pp. 311–313.
‡ *The Engineering Record*, Vol. XL, p. 294.

lb. Two cubes exposed to −15° fahr., and tested after 28 days, crushed at 115 000 lb. Two cubes exposed to —15° fahr., for 28 days, and then kept in warm room for 28 days more and tested, stood over 185 000 lb. Two cubes mixed with salt-water (1 pint of salt to 10 quarts of water) and exposed to —15° fahr., and tested after 28 days, stood over 185 000 lb. Mr. Rogers concludes that freezing before setting does not injure Portland cement concrete, even if, after having frozen hard, it is exposed to alternate freezing and thawing, and that the use of salt largely counteracts the effect of cold in causing slow hardening. Similar tests were made on cubes of Louisville cement concrete and with the same conclusions, except that salt was not beneficial. Mr. James S. Costigan read a paper before the Canadian Society of Civil Engineers, giving the result of 15 sets of tests on cement briquettes exposed to different conditions of freezing and thawing, and found but little, if any, loss of strength by freezing.

A large number of tests have been made which appear to show that freezing does injure Portland, or Natural cement concrete. Percy L. Barker and Henry A. Simonds, as a result of 7 150 tests,* conclude that Portland cement mortar suffers no surface disintegration, but that strength is sometimes injured as much as 40% by freezing. Specimens mixed with water containing 1 part salt to 15 parts water by weight gave best results and suffered but little loss of strength by freezing. Experiments† made by E. H. Conner at Cairo, Ill., found that the addition of salt increased the strength of Portland cement concrete. Mr. A. G. Fogg, who experimented on Portland cement mortar exposed to alternate freezing and thawing, concluded that a quick-setting mortar may freeze in twelve hours without injury, but that it is not safe to allow a slow-setting mortar to freeze in less than four days. None of these tests are conclusive, and none of them, as far as the writer has been able to discover, prove that Portland cement mortar or concrete is permanently injured by freezing or alternate freezing and thawing. It is well known that freezing greatly delays setting, and it is manifestly unfair to compare a test-piece which has been frozen for 27 days and thawed out on the 28th day, with one which has remained

* *Engineering News*, Vol. XXXIII, p. 288.
† *Engineering News*, Vol. XXV, p. 99.

in the testing-room 28 days, and to conclude that freezing has injured the concrete to the extent of the difference shown. It would be much nearer the truth to assume that setting was suspended for the length of time that the specimen was frozen, and to allow the frozen specimen the same length of time in the testing-room as the unfrozen specimen before testing and comparing results. Very few engineers place much reliance on the tensile strength of concrete, and compression tests on cubes would have much greater value than tension or transverse tests. The tests made by Mr. Rogers, of the Chicago, Milwaukee and St. Paul Railroad, previously referred to, are in the right direction, and if his machine had been able to crush the specimens in all cases, it would have nearly settled the question of the advisability of laying concrete in freezing weather, and the Committee on Uniform Tests of Cement of the American Society of Civil Engineers cannot do a better service than to continue experiments on that line.

It is quite customary in laying concrete in freezing weather to either heat the materials before mixing, or to let steam and hot water into the mixing box, the concrete being deposited quite frequently when very hot. W. W. Maclay, M. Am. Soc. C. E., made many experiments,* from which he concluded that this is not good practice. Two sets of briquettes of 1:2 mortar were made, one at 40° and the other at 100°, exposed to freezing weather, and tested in 28 days. The 100° specimens gave a strength of only 30% of the 40° specimens. Experiments on 1:2:5 concrete gave similar results, and experiments on neat cement worse results. He considers that materials should not be heated except to thaw the frost out of the stone and sand. All specimens mixed cold seemed to set and not to freeze in temperature of 13°, but hot concrete, on the contrary, invariably froze, and specimens placed in water always dissolved. He considers that no good work can be done under water in winter when the materials are heated. Those tests were made 27 years ago with Burham cement, and mostly with neat cement at age of 7 days, and are not conclusive. Further tests in this direction are much needed, using modern concrete tested in compression, and subjected, as nearly as possible, to the same conditions met with in ordinary

* *Transactions*, Am. Soc. C. E., Vol. VI, p. 311.

winter practice. Heated concrete laid in freezing weather is usually deposited in wooden moulds, which protect it to a great extent against frost. It is also covered at night, and, as far as practicable, as the work progresses during the day, and there is considerable evidence which appears to show that such work is good. The Melan Bridge, at Mishawaka, Ind., previously referred to (3 spans of 110 ft. each), Alonzo J. Hammond, M. Am. Soc. C. E., Engineer in Charge, was built between October 26th, 1903, and February 25th, 1904, in temperatures ranging from 0 to 55° above. The concrete was heated by admitting hot water to the mixer and was deposited at about blood heat, and retained sufficient heat after 48 hours to melt snow. The center arch was completed on February 13th, 1904, temperature about 25° fahr.; on February 14th, the temperature dropped to 0°, and on March 1st, or 15 days after completion, an ice jam took out the centering and left the arch unsupported. No bad effects could be observed, and the settlement of the arch was but little more than for the other spans when the centerings were removed later in the regular way. If the concrete had not been heated, it would be interesting to know whether the result, under such trying conditions, would not have been much worse.

Theories for Reinforced Concrete Beams.—Quite a number of theories or formulas have been advanced for the calculation of concrete-steel beams, most of them based on the common theory of flexure, with no allowance made for tension in the concrete, and the belief is quite general among the highest authorities on reinforced concrete in all parts of the world, that such theories are the safest and best. The writer has compiled the results of quite a large number of experiments on beams, in which the ratio of length to effective depth ranged from 6.0 to 22.2, the ultimate strength of metal, from 50 000 to 100 000 lb. per sq. in., the area of metal, from 0.31 to 3.9%, and the age of concrete, from 23 to 90 days, and in each set of tests compared the results agreed with theory as closely as would have been the case with steel beams; but such results cannot always be expected, as the modulus of elasticity of concrete, which enters into the calculation, is rather an uncertain quantity, depending on the quality of ingredient, mixture, mixing and placing, age and stress. Professor Melan makes a distinction

between the modulus of elasticity and modulus of deformation, and considers that the latter, which is less than the modulus of elasticity by the amount corresponding to permanent set, should be used. Permanent set also causes internal stresses in beams after the load has been removed, so that any theory may be regarded only as an approximation.

The French Government appointed a commission of experts to establish a building code for concrete-steel structures. The steel reinforcement is considered as taking the whole tensile stress. The Prussian regulations for reinforced concrete buildings, issued by the Minister of Public Works of Prussia, provide that the steel shall be considered as taking the entire tensile stress in beams. The regulations of the Bureau of Buildings of the Borough of Manhattan require the same thing, and, as far as the writer knows, this is true of all other cities which have formulated rules on the subject.

The opinion that the tensile strength of concrete should not be considered, is much strengthened by the result of experiments on concrete-steel beams, made by F. E. Turneaure, Assoc. M. Am. Soc. C. E., and given at the annual meeting of the American Society for Testing Materials, July, 1904. The beams were tested with the tension side up, and cracks first appeared at a certain amount of deflection, whether steel was present or not. With 1:2:4 concrete minute cracks were first observed at an elongation of 0.0001 to 0.00015; they were visible to the naked eye (if the beam was dry) at an elongation of 0.0004 to 0.0005 (12 000 to 15 000 lb. per sq. in. in the steel), and then generally extended across the tension surface and some distance along the sides of the beam. These results show clearly that the concrete loses its tensile resistance at an early stage of the loading.

Literature.—There is little literature in English on the subject of concrete-steel, it being in this respect much behind that of some other countries. The English works of Sutcliffe, Newman and Potter are not up to date. Quite a number of good articles have appeared in engineering papers, and quite a number of translations of articles in foreign publications have been made and published in the United States, but there are no American publications devoted to this subject, and no standard works of reference. The writer understands

that a monthly publication, devoted exclusively to the subject of concrete and concrete-steel, will soon be published in New York City, and that a comprehensive work on reinforced concrete, by A. W. Buel and C. S. Hill, of New York City, is now in press, so that present conditions are likely to be improved in the near future.

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CONCRETE AND CONCRETE-STEEL.

CONCRETE AND CONCRETE-STEEL IN THE UNITED STATES.

By John S. Sewell, Capt., Corps of Engrs., U. S. A.

The writer would begin this paper by suggesting a change in the title of its subject. The term "Concrete-Steel" seems to him entirely without meaning, apart from its definition. It is certainly not descriptive of the peculiar type of construction to which it is applied. The term "Reinforced Concrete," on the other hand, is fairly well descriptive, and therefore practically defines itself. It is no more awkward to use than "Concrete-Steel," and is more in accordance with the genius of the English language. Both terms are in use, but one must ultimately prevail over the other. There is still time to choose between them, however, and the question is submitted to the judgment of English-speaking engineers whether the more descriptive term is not the better one. The German term, "Beton-Eisen," seems open to the same objections as "Concrete-Steel"; they are seemingly literal translations of each other. The French term, "Béton-Armé," is descriptive, but apparently not so accurate, as the English term, "Reinforced Concrete." It would seem, therefore, that nothing will be gained by translating it directly

into English, literally or otherwise, though "Reinforced Concrete" might be considered a rather liberal translation of "Béton-Armé."

In discussing the uses of concrete, reinforced or otherwise, the writer will confine himself practically to those applications which are exemplified in the work of his own Corps.

Concrete.

The use of concrete by the Corps of Engineers of the United States Army began very early in the history of American engineering. This corps was probably the pioneer user of concrete on a large scale in the United States. In the early days, concrete was used principally for foundations, and, possibly, for backing up other masonry. Later, it was used for the masonry of underground passages in fortifications, and, in some instances, where stone was difficult to obtain, for the more important parts of the works themselves. Still later—within the life of the present generation—the development of modern ordnance has made a degree of protection necessary for land guns, which can no longer be obtained at reasonable expense with cut stone, nor within reasonable thicknesses with earth alone. For this reason, and because concrete is expected not to splinter as badly as stone under impact, the body of the parapet of modern batteries is made of concrete. This has involved its use in extremely large masses, containing thousands of cubic yards. From experience with large masses applied in this way, it was an easy step to its use for lock masonry, superstructures of breakwaters, etc. Concrete dams have often been proposed, and several have been built in the United States. One of the earliest of which the writer has any knowledge was built under the direction of the officers of the Ordnance Corps, U. S. Army, at Rock Island, Ill., a few years ago. Several reservoir dams have since been built of concrete by Engineer Officers. The first use of concrete for an entire lock was on the Illinois and Mississippi Canal, in 1894, under the direction of Lieut.-Col. (then Capt.) W. S. Marshall, of the Corps of Engineers. Within the last few years, concrete in large masses has been used by the railroads of America, for abutments, retaining walls, and bridge piers, and it has also been used for bridges, viaducts, and even elevated aqueducts. Examples of the

last three classes of work are to be found in the work of Major H. M. Chittenden, Corps of Engineers, U. S. Army, in the Yellowstone National Park, during the fiscal year ended June 30th, 1903. Concrete superstructures for breakwaters have been built at Marquette, Duluth, and Buffalo; and concrete locks have been adopted in a number of projects for the canalization of rivers.

Concrete is used also in connection with footings made of steel beams or rails, for the preservation of the metal from corrosion; it is used for the fire-resisting covering of the steel-frame superstructures in modern buildings; it has been used for filling closed columns, to prevent rust, and to stiffen the columns. Very recently it has been used for piles, where timber would be subject to decay. In such cases, the pile, if of simple concrete, is built in place. Finally, the walls of buildings have been constructed, in whole, or in part, of simple concrete, where a considerable thickness was desired, and other forms of masonry were more expensive.

Until the recent great development of the Portland cement industry in the United States, the greater portion of concrete work was executed with the so-called natural cements, of the Rosendale, or Roman, class, which, owing to an abundant supply of peculiarly good raw material, have always been obtainable of excellent quality in the United States. Portland cement was used only where special strength, or hardness, or resistance to abrasion was required. At the present time, the low cost of Portland cement has caused its use for concrete to be greatly extended; a concrete of given strength can generally be made more cheaply with Portland cement than with Rosendale. There have been instances where, in the interior of a large mass, a natural cement has failed to set, even after many years, although it was tested carefully during construction. The writer knows of no failure of Portland cement to set under similar circumstances. On the other hand, much of the work, both old and new, executed in natural cement, has attained a degree of strength that it would not be safe to expect from the best Portland; and natural cements seem not to give the trouble from disintegration after setting, due to causes within themselves, or to exposure to sea water, that is experienced occasionally with Portlands. The manufacture of both classes of cement has been improved greatly in recent years, and good concrete can be made with either; but where

exposure to the weather, or great resistance to abrasion, is necessary. Portland cement is generally, but not always, used.

It has always been realized that an ideal concrete was one in which all the interstices of the sand, or finer parts of the aggregate, were filled with cement, and all the larger voids were filled with the mortar thus formed. Until recently, many American engineers considered that stone or gravel of uniform size was quite necessary to the best results; for a number of years, however, many officers of the Corps of Engineers have used a graded aggregate, thus securing a better result with less cement. The writer believes that this is now generally regarded as the best practice. The usual custom, when using broken stone, is to insist upon having the run of the crusher, excluding only the fine dust; in using gravel, broken bricks, or other aggregate, the attempt is always made to secure a variety of sizes. The finer part of the aggregate is generally made up of coarse sand, in case there is a deficiency, as there usually is.

Some experiments have shown that crusher dust is often a desirable part of the mixture; but this depends somewhat upon the kind of stone used. The writer has had some experience with crushed gneiss, in which the dust consisted largely of minute flakes of mica, which, when wet, behaved like quicksand. This dust, when used in any quantity, invariably "killed" the cement, so that it hardly set at all. This case was special, however, and there is little doubt that it is, for most kinds of stone, a waste of time and money to exclude the dust, unless there is a demand for it as a commodity in itself.

As a rule, where sand is used, it is specified to be sharp and clean; whether sharpness is requisite, is open to question. Many tests made with the same cement, but some with a rounded river sand and others with sharp, crushed quartz sand, have shown a decided superiority for the rounded sand. Whether this is general, however, has not been established. There have been tests made with crushed glass which gave higher tensile strength than the quartz sand.

There are many indications, also, that a small amount of clay or loam in the sand or other parts of the aggregate, in no way diminishes the strength of the concrete. Major Chittenden's work in the Yellowstone Park, previously referred to, yielded strong evidence

to this effect. The writer has had similar experience in his own work, where rather dirty sand gave, as far as could be determined, just as good results as cleaner sand, when the two were used side by side, with the same cement. There is a patented wall plaster for sale in the American market, which is said to consist of a small proportion of cement, and a large proportion of clay. It is claimed that it gets very hard, and is very durable. If this is true, it is more evidence that a reasonable amount of clay or loam in concrete is not harmful, so far as strength and hardness go. It is not yet settled, however, that the weathering qualities of the concrete will not be impaired; until it is, it is preferable to have the sand and other materials as clean as possible.

In the early days of concrete making, rather dry mixtures were nearly always specified, because laboratory tests had indicated that they gave better results than wet ones. But practice has shown that the thorough mixing and ramming, especially the latter, required to develop these higher results, are very difficult to secure in actual construction work. Better results, therefore, are obtained in the field with a mixture wet enough to quake decidedly after moderate ramming. The tendency at the present time in the United States is rather toward extreme wetness, largely due to the advantage of wet mixtures in reinforced concrete, and in works where impermeability is desired. But for all other purposes, better concrete will result from a mixture requiring reasonable ramming to make it quake—therefore susceptible of some consolidation after placing. As "drowning" seriously injures the best cements, sometimes wholly preventing them from setting, the use of more water than is necessary for reasonable plasticity should be prohibited.

At first, all concrete was mixed by hand; but from the earliest days, inventors have tried to produce machines to do the mixing. The economy of machine mixing has often been over-estimated, however, and many contractors have suffered severe loss from this mistake. An analysis of the cost of mixing and placing concrete by hand will show that, in the majority of cases, the cost of mere mixing is not more than 20 to 25% of the whole. Unless with the mixer is installed a plant capable of effecting considerable economy in the handling of materials to the point of mixing and of the concrete after mixing, the only advantage of the mixer is apt to be an

improvement in the quality of the product, with a possible economy in cement. In any case, it requires a rather large amount of concrete to pay for a mixing plant, and this fact is not always appreciated.

All the concrete mixers used in the United States may be divided into two classes—continuous mixers and batch mixers. Officers of the Corps of Engineers have generally avoided continuous mixers, notwithstanding the small cost attendant upon the use of some types, because of the difficulty of securing uniform proportions in the product. Of batch mixers, one of the earliest and best, so far as quality of product was concerned, was the revolving cube, which, the writer believes, was first used by officers of the Corps of Engineers. Various types of revolving drums, double cones, cubes, etc., have been devised to facilitate the operations of charging and emptying, which were somewhat tedious in the early form of cubical mixer. Recently a batch mixer consisting of a revolving annular pan, in which two or more sets of stationary plowshares effect the mixing, has been put upon the market. In thoroughness of mixture it is unexcelled, and it is equally good for mortar or concrete. This is not true of the revolving drums and cubes, none of which are reliable mortar mixers. The economy of operating the revolving-pan mixer, under favorable conditions, seems to be as great as that of the average batch mixer, and its thoroughness would seem to justify a certain economy in the use of cement.

Where officers of the Corps of Engineers have built locks, or the superstructures of breakwaters, of concrete, all subaqueous parts are usually built of blocks moulded out of water, and placed after hardening; the parts above water have been usually divided into sections small enough to be completed in one day's work, and these have been built in place, as independent monoliths.

In the case of dams or lock walls, where the joints were to be water-tight, corresponding grooves have generally been left on the abutting surfaces of adjacent monoliths, thus forming holes which were afterward filled with soft asphalt, or by stock-ramming with clay, or by means of soft wood timbers, treated to prevent decay, and grouted in. In some cases, sheets of lead have been built into both monoliths across the joints. All these devices, when carefully executed, have been successful.

In fortification work, there are some objections to dividing the concrete into small monoliths, and the entire mass has been built as one. But in a good many cases, seepage through the concrete into the interior magazines and passages, together with condensation, has given considerable trouble in the new fortifications. This trouble has been overcome in various ways, but as papers on "Fortifications" are due from two very able officers who have been most sucessful in the solution of this problem, details will be omitted from this paper. One method, however, which, the writer understands, has been successful, will be described, because it would be of general application if its success is really assured. It consists in finishing the extreme top surface of the concrete over the passages and rooms below, with a rich, dense, granolithic concrete, laid in small independent squares, and reinforced against cracking by small steel bars running both ways of the slabs. The joints between slabs are caulked just like the seams of a wooden deck, and the whole exposed surface is given a sufficient slope to shed water quickly. Under these conditions, water does not pass through the slabs themselves, and the joints can be kept tight with a little care. The granolithic work need be only about 3 in. thick.

The experience of the Corps of Engineers, generally, confirms the prevailing opinion that steel, properly embedded in concrete, is protected from corrosion. There has been some evidence, however, that if the concrete is mixed with salt water, or with sand from the seashore, and is not kept dry after setting, the steel will corrode. At any rate, there have been several cases of rapid and complete corrosion of embedded steel, where this seemed the only plausible explanation. Some experiments on a small scale, made under the writer's direction, seem to lend probability to the theory that salt in the concrete will corrode the steel, but they were not sufficient to confirm it, in general terms.

Another possible explanation of the failures in actual work is this: the metal that was corroded was expanded metal, protected from the outer air, in a damp place, by about 1 in. of concrete. A prominent maker of terne plates in the United States has informed the writer that ordinary stock steel plates often contain within themselves impurities gathered from the slag during the process of manufacture, which insure the destruction of the plates in damp places,

regardless of any protective covering. As expanded metal is often made of stock material, the particular lots which failed may have suffered from their own impurities.

The writer has used concrete for filling hollow steel columns in building work, with the double object of stiffening the columns and protecting the interior from corrosion. While the stiffening effect of a concrete filling on a steel column cannot be exactly determined, it would seem entirely justifiable, in the case of columns of the lengths that occur ordinarily in buildings, to design them in simple compression, without any allowance for flexure, if they are filled with concrete. The saving in steel will often more than pay for the filling; moreover, even without any outer fire-resisting covering, the filled column would certainly be much more rigid in a fire than it would if not filled.

The question of fire-resisting construction is of more importance in the United States than in Europe, because of the greater prevalence of destructive fires and the greater use of steel for buildings. Concrete for the fire-resisting parts of structures, including floor arches or floor plates, as well as coverings for columns, girders, and beams, has been growing in favor for a number of years, notwithstanding a vigorous campaign against it on the part of those commercially interested in competing materials. An ideal fire-resisting material for use in floor arches and for protecting the structural steel members of a building should fulfil the following conditions:

1.—It should undergo no molecular change in a fire.

2.—It should be a poor conductor of heat.

3.—It should be possessed of sufficient mechanical strength, not only to withstand ordinary structural strains, but also the strains set up by sudden and unequal heating and cooling, as in a fire, with hose streams playing upon it.

Such a material properly applied will not only protect the structural metal from undue expansion and from distortion and failure, but it will itself be intact after many ordeals of fire and water.

No material entirely meets the first requirement, and, therefore, no material can indefinitely meet the third. Well-burned clay, properly applied, meets all three requirements sufficiently well, however, for all practical purposes. Its most efficient form is good common brickwork, laid in cement mortar; the bricks should be of very re-

fractory clay, however, and, for the best results, should be made porous by the addition of sawdust to the clay, during the process of pugging. But brickwork entails considerable weight, as well as segmental floor arches, to which architects object on the score of appearances.

Burned clay or terra cotta is ordinarily applied, therefore, in the form of very light hollow tiles, which give flat arches; these are too flimsy to meet the third requirement; they protect the steel, but suffer serious loss themselves. To make them as efficient as brickwork they would have to be just as heavy.

Concrete of various grades covers the entire ground between brickwork and commercial hollow tiles, so far as efficiency goes. Subjected to heat, the cement in concrete gradually loses its water of crystallization, and with it, much of its strength. But in actual fires this process is very slow. Usually only one face of the concrete is exposed, and on broad, flat, or gently curving surfaces, the calcination makes little progress. There was enough concrete work exposed to the fire in the great conflagration at Baltimore to give a fair idea of its behavior. On broad surfaces, such as those described, the dehydration had not noticeably progressed anywhere to a greater depth than $\frac{1}{2}$ in., and generally the damage was limited to a depth of $\frac{1}{4}$ in., or less. The damaged material showed no disposition to come off, and would have answered perfectly well as a base for a new plaster finish. On exposed salient corners, where the heat was intense, the damage was deeper; the concrete spalled off, showing a tendency to round the corner to a radius of 2 in. or more. Even good brickwork suffered from this in many cases.

Where concrete is used for fire-resisting constructions, a surplus thickness of at least an inch should be allowed, over and above all structural requirements, and all salient angles should be rounded to a radius of at least 3 in. If this is done it is quite certain that good concrete will come through a number of fires before total renewal or extensive repairs will be necessary. Many tests of concrete have been made by heating small specimens entirely through, to a temperature of 1 000° fahr., or more. They have been cooled, both slowly and suddenly. Most of them show severe damage; but this test is not at all typical of what occurs in a fire. Very few bricks will stand it any better than concrete, but they are good fire-

resisting material, just the same. If the covering of the steel members of a building is subjected to a sufficiently long and intense heat to admit of a uniform temperature of 1 000° fahr., the structure is almost certainly doomed to total collapse, in any case; but no fire in a building would ever produce such a condition on a large scale.

Notwithstanding the severity of the tests described, specimens of concrete made from clean, coarse-clinkered cinders came through with little damage. Many fires and other fire tests have shown that good cinder concrete, free of combustible matter, has a marvelous resistance to fire. The writer is inclined to think that, at its best, it is the very best available fire-resisting material. The chief and fatal objection to its general use is the impossibility of securing an adequate supply of the right kind of cinders.

As an instance of the fire-resisting qualities of special concrete, the writer knows of at least one large Portland cement mill using rotary kilns and the dry process, where the lining of the kilns is composed of bricks moulded from a concrete made of the cement clinker and neat cement. This lining is said to be better, dollar for dollar, than the best fire-brick. Possibly, in this case, and in the case of cinder concrete, the cement may, after dehydration, become reclinkered, and form as close a union with the aggregate, as it did during the process of crystallization.

It seems probable that broken slag and broken bricks or terra cotta are better aggregates for fire-resisting concrete than stone; gravel also is probably better than stone, but possibly not so good as bricks or slag. The gravel is composed of bits of stone which, through ages of exposure, have cracked and broken through all weak spots, such as incipient fissures, air and moisture cavities, etc. When stone is broken in a crusher, the fracture does not always pass through such loci of weakness; the small bits of stone are, therefore, just as liable to spall when heated as larger pieces from the same quarry.

One objection often raised to the use of concrete in lieu of more expensive masonry, or in lieu of other materials, is the danger of poor work. The writer has never been able to see the force of this argument. Very simple and inexpensive precautions will insure a proper amount of cement and reasonably good mixing; against other forms of carelessness, and even of viciousness, the material pro-

tects itself. It automatically adjusts itself to inequalities of bed or bearing, and it requires a positive expenditure of time and money to prevent it from attaining a reasonable strength, except where it is exposed to dry, warm air, in thin layers; here again, very simple and inexpensive precautions will prevent damage.

Many building ordinances and many specifications in the United States require the use of granite blocks for capping wooden piles, and on top of concrete footings, for the reception of metal column bases. Such blocks are almost never properly bedded, so that the advantage of their great crushing strength is neutralized by the stresses due to transverse strains that are not supposed to exist. The writer thinks that rich Portland cement concrete is better and cheaper in both places; it will at least bed itself accurately, and in a country where the economy of good workmanship is still appreciated so little as it is here—especially in the erection of buildings—this is a great advantage.

In the use of simple concrete piles, built in position, two methods have been employed in the United States—both being patented, in whole or in part. One method consists in driving a tapering, collapsible form, covered with a closely-fitting metal shell. After driving, the form is caused to collapse, and is withdrawn, and the metal shell is filled with concrete. The collapsible forms are very heavy, and have too much mass to drive easily with an ordinary hammer; they are put down with a water-jet, wherever possible, for this reason. They are not practicable in all situations, and the writer is under the impression that difficulties of handling and driving limit them to an extreme length less than 40 ft. in all cases. They have their own sphere of usefulness, however, in situations where driving is easy and lengths moderate.

The other method of building concrete piles in place was first used on the work of reconstruction of Washington Barracks, D. C., of which the writer has charge. It consists essentially in driving a form composed of a concrete point and a steel tube, with a hardwood driving head, to the desired depth; the tube is withdrawn, and concrete is introduced so as to keep the bottom of the tube sealed during the process of withdrawal, and so as to fill the hole with concrete before the sides have an opportunity to cave in. In some cases the heavy tube used for driving was fitted over a tenon on the upper

end of the concrete point, and was inside of another lighter shell, of the same exterior diameter, as the desired pile. This arrangement permitted the pile driver to work well ahead of the filling gang, without necessitating too great an outlay in heavy "driving forms," as the inner tubes were called. The concrete piles at Washington Barracks have been entirely successful. They have been loaded with as much as 26 tons on a 16-in. pile, driven 40 ft. through soft mud into sand, and have carried the load for several weeks with a settlement not exceeding $\frac{1}{4}$ in. One large barrack building, nearly 250 ft. long, has its two ends on firm ground, while its central part is over an old inlet from a creek that formerly flowed into the Potomac River, near by. In the middle, the old inlet is filled with 40 ft. of mud. The central part of the building is on concrete piles driven to the sand beneath the mud. The ends are on ordinary concrete footings. Two very small hair cracks, which appeared when the building was half done, over the middle of the old inlet, and which have since closed up of themselves, are the only signs of unequal settlement. Concrete piles were used at Washington Barracks because the situation was one in which wooden piles would decay, unless cut off below the level of mean low water; this would have involved deep excavations and heavy concrete footings for the walls, on top of the piles. The material above mean low water was mostly made earth, which settled seriously under loads of 500 lb. per sq. ft., and which was very treacherous in deep trenches. Experience at Washington Barracks indicates that where the necessary excavation is as deep as 10 ft., even if hard bottom exists at that depth so that wooden piles are not required, there is an economy in the use of concrete piles, if thereby the deep trenches and solid concrete filling for them can be avoided.

The opinion has become rather prevalent in the United States of late years that freezing, and even alternate freezing and thawing, will not injure Portland cement concrete. There have been cases where the cement set up very well, notwithstanding the fact that it was frozen, not only once, but several times, during the process of setting. The writer has had several such experiences in his own work. But there have been more cases where even a little frost has done undeniable damage; and in a very recent case, where a slab of concrete was frozen entirely through within a short time

after placing, and remained frozen for several weeks, it was practically ruined, although it did not freeze again after it once thawed. Concrete put in at the same time, of the same cement, which escaped freezing, set in a perfectly normal manner, and attained its full strength. It would seem, therefore, that to do concrete work in freezing weather is too hazardous for safe practice. If the concrete can be prevented from freezing, however, it matters not what the temperature of the air may be.

Reinforced Concrete.

This type of construction has been much less developed in the United States than in Europe—until within the last few years, at any rate. Yet some of the earliest examples of its use are to be found in this country. The great development of the steel industry, and the satisfactory results following the use of steel for structural purposes, has, no doubt, had much to do with the slowness of American engineers to adopt the new form of construction. It is now being very generally applied, however, and bids fair to displace steel in many cases. Its use for the floors of buildings began very early; this was soon extended to include footings requiring a large bearing area on the soil, and then to walls, and columns, as well as floors. For a number of years, reinforced concrete has been used in fortification work to support the great masses of masonry above the ceilings of interior magazines, passages, etc. Its use in buildings has been greatly extended, and it is also used now for arched bridges, sewers, culverts, dams, retaining walls, piles, and nearly every form of structure for which timber, steel or masonry is suitable. It is even proposed to build moderate-span girder bridges of it on railroads, for high-speed trains; and viaducts of it have been often proposed, though the writer is not aware of any that have been built.

At least one reinforced-concrete dam is under contract, in the project for the canalization of the Kentucky River, under the direction of the Corps of Engineers; others have been designed for other localities, and will no doubt be constructed in the near future. The general type of design for these structures shows a triangular cross-section, with a vertical face on the up-stream side and a sloping face on the down-stream side; the dam is hollow, but has diaphragm walls at intervals; the walls of the interior cells are reinforced to

withstand the various bending strains to which they may be subjected, and the dam itself is well anchored to its rock foundation to prevent sliding or overturning, although it usually has mass enough to prevent the latter catastrophe. Reinforced concrete has also been used freely in buildings erected under the supervision of the Corps of Engineers, for floor and ceiling slabs, supported by steel beams, for complete floor systems, including columns, girders, beams, and floor slabs, and for stairways. It has also been used by the Quartermaster's Department of the Army for water tanks and towers, and by the municipal government of the District of Columbia for coal pockets. Some of the longer concrete piles at Washington Barracks were reinforced against flexure by means of a single, central longitudinal steel rod; it was feared that where the pile passed through soft mud it would not receive sufficient lateral support from the material around it to prevent bending. All of the piles had concrete points, which were reinforced against the crushing effect of driving by means of expanded metal or wire lathing, disposed in much the same way as the spiral windings of the hooped concrete developed by M. Considère.

By far the most common use of reinforced concrete in the United States has been for floor slabs or arches, supported by steel beams. This feature of the construction of buildings has been the subject of innumerable patents for so-called "systems," which, with few exceptions, have had little to recommend them from the point of view of structural design or fire resistance. Most of them were designed by purely empirical methods, in many cases by so-called "practical" men, who not only had no training as engineers, but who had not even the good mechanic's clear conception of the parts played by the concrete and its steel reinforcement. Architects have not, as a rule, familiarized themselves with the principles of the new construction, and municipal building departments have approved the various "systems" for use, after certain loading tests—sometimes including fire tests—without regard to any rational method of design for adapting them to varying spans and loads. It is needless to say that the well-considered design has generally been at a disadvantage under such conditions. Approved plans have often shown no details of floor construction, beyond a note to the effect that such a "system" was to be used, and the specifications have been no more explicit. Within the last three years, however, there is a

noticeable improvement in these matters. At least one large city has adopted regulations which, while incomplete and wholly empirical in their nature, should result in fairly safe designs.

Even the self-confident American contractor has not often tried to design and erect entire structures in reinforced concrete, involving columns, girders, and beams, as well as floor slabs, unless, by training, or careful study of his subject, he was really possessed of reliable knowledge of its principles. The foremost of such men in practical achievement, before the introduction of systems founded on the Hennebique, was E. L. Ransome, Assoc. Am. Soc. C. E., who has done much excellent work. Within three or four years, the Hennebique system has been introduced into the United States, and a number of systems very similar to it have been developed, and applied on a rather large scale.

On the theoretical side of the subject, no such exhaustive treatise on the state of the art as that by M. Christophe has been produced in the United States; nor has any American engineer made such elaborate investigations as those by M. Considère, and other European investigators.

But the theory of reinforced concrete is now engaging the time and attention of many competent engineers; reliable data are being rapidly accumulated, and the writer thinks that real additions to the correct working theory have been made in this country.

As the main object of reinforcing concrete is to enable it to withstand the strains due to transverse loading, the point of first interest in the development of a working theory is a formula or set of formulas, for the design of the section of a beam, girder, or slab, where the bending moment is a maximum.

In attempting to develop a rational formula for this purpose, all engineers, so far as the writer is aware, have made the following assumptions:

1.—Sections plane before bending remain plane after bending, at least within the limit of elasticity of the steel.

2.—There is such a union between the steel and the concrete, in a well-considered design, that the two materials will act together.

3.—There are no initial strains, in either the steel or the concrete, due to change of volume of the concrete in setting.

In addition to these, another assumption is always made, as to

the form of the stress-strain curve of concrete in compression, and sometimes, also, in tension.

Some engineers neglect the influence of concrete in tension, while others do not.

There is experimental evidence to show that assumption No. 1 is practically correct. No. 2 is correct, if the design is properly developed; but as a matter of fact, many designs have too little concrete below the steel, when the latter is used only in the form of horizontal bars, to justify the assumption. It is quite certain that a considerable mass of surrounding concrete is necessary to develop the strength of the steel, even up to its elastic limit.

The experiments of M. Considère and others indicate that assumption No. 3 is not correct, but under the ordinary conditions of practice, no dangerous error is introduced by it; any other assumption would introduce great complications, without in the least diminishing the probable or possible error.

The trend of conservative opinion in the United States seems to be toward neglecting the tensile strength of the concrete, and assuming that the steel carries all the tensile stress.

A number of assumptions have been made as to the form of the stress-strain curve of concrete in compression; one is that it is a parabola, having its axis perpendicular to the direction of the applied forces, and its vertex on the extreme outer element of concrete in compression at a certain stage of the loading—usually that where the stress in this extreme outer element of concrete is equal to the ultimate strength. The applied forces are always assumed to be parallel to each other, and perpendicular to the axis of the beam, girder, or slab, before bending.

Another assumption is that the stress-strain curve is a parabola, with its vertex on the neutral axis of the piece, and its own axis at right angles thereto.

Another assumption makes the stress-strain curve a right line, while others make it an empirical curve, derived from plotting the results of actual tests.

In the reports of "Tests of Metals, etc.," at the Watertown Arsenal, for the years 1898 and 1899, are recorded the results of several hundred compression tests on cubes and prisms made of concrete of varying proportions, of neat cement, and of mortar.

The total deformation and the permanent set are given for various loadings, from no load to the ultimate strength. The increments of load are, as a rule, 100 lb. per sq. in. up to 1 000 lb. per sq. in., and from that point, 200 lb. per sq. in. In a few cases, the observations were recorded for uniform increments of 100 lb. per sq. in. Evidently, for each recorded load, the total compression was read, then the load was reduced to zero, and the set was measured; the load was then repeated and increased to the next higher one, and so on. Thus a considerable percentage of the inelastic compression must have been removed, though not all of it. The cubes and prisms were all of considerable size—some 12 by 12 in., and others 10 by 10 in., in cross-section. The proportions and methods of mixing were evidently such as might be expected in practice, except that some of the specimens were much richer in cement than would be the case in actual work.

For some time, the writer has been studying these tests with a view to deducing what he could that would be of value in design. It has been impossible to complete this study up to the present time, but certain conclusions seem to follow from what has been done, and as they bear very directly on the subject in hand, they may be of interest.

In studying the tests, the elastic compression per unit of length, and the value of the modulus of elasticity for each recorded load, in each test, have been determined from the data given—the modulus of elasticity being based on the elastic compression, in each case. The object of the study was to determine, if possible, the laws governing the relations between the elastic compression, the stress, and the modulus of elasticity.

It is thought that these tests more nearly represent the conditions existing in actual structures than tests such as those made by Professor Bach, and described in M. Christophe's work on reinforced concrete.* It is not probable that within the range of loads repeated in actual structures, the inelastic deformations are ever eliminated so completely as in Professor Bach's experiments. It is even doubtful whether they are eliminated so completely as in the Watertown tests. The real factor of safety may therefore be determined with more probable accuracy by the use of constants

*"Le Béton Armé et Ses Applications," par Paul Christophe, Paris et Liège, 1902, pp. 470 *et seq.*

or functions derived from these tests than by the use of Professor Bach's results.

Let the modulus of elasticity of concrete in compression be represented by E; it is variable, and its initial value may be represented by E_0. Let the compressive stress, in pounds per square inch, be represented by F. Let f_c be the ultimate compressive strength of concrete, in pounds per square inch. Let S represent the elastic compression, or strain, per unit of length.

A study of the Watertown tests indicates that E is a decreasing function of F, but with a much more rapid rate than is given by Professor Bach.

The individual tests give curves that are often very irregular; but by combining a number of tests, the resultant curves become much more regular. This regularity is more marked in concretes of moderate strength than in concretes of high strength. Mortar and neat cement give more erratic curves than concrete, and the rate of decrease is much less for them than for concrete. Probably the reason for the erratic curves obtained when the proportion of cement is high, is the existence, under such conditions, of setting strains, from which leaner mixtures are free. The constants which determine the form of the curves seem to be, for concretes of varying strength, functions of the ultimate strength, so that, in order to determine the true form of the function, it is necessary to group the tests according to ultimate strength. In all cases, the initial part of the E–F curve looks much like an equilateral hyperbola; in concretes of moderate strength, *i. e.*, from 2 000 to 3 000 lb. per sq. in., the part of the curve corresponding to stresses higher than about 600 lb. per sq. in. is best averaged by a straight line; in fact, in many cases, it is almost absolutely straight. If this straight line be produced backward until it cuts the axis of E, and the intercept be called E_0, it will be found that E_0 is a little more than twice as great as the value of E when $F = f_c$. For concretes of higher ultimate strengths, *i. e.*, above 3 000 lb. per sq. in., the E–F curve can be averaged as well by a hyperbola as by a straight line; it is rather irregular near the vertex of the hyperbola and reverses its curvature, so as to give values of E greater than the ordinates to the hyperbola. If a straight line be used to average the curve, it will be found to give about the same relation between E_0 and the value of E for $F = f_c$, as in the case of concretes of lower strength.

But the entire *E–F* curve for the stronger concretes is above that for the weaker concretes.

The *S–F* curve, in all cases, looks more like a hyperbola than any other curve. The *S–E* curve also seems to follow a hyperbolic law, though probably its equation, if deduced, would not be of the second degree.

To illustrate these conclusions, the curves corresponding to a group of twelve tests of specimens with an ultimate strength of 2 500 lb. per sq. in., from the report of 1899, are shown in Fig. 2. These curves are selected because they are typical, quite regular, and seem to disclose the fundamental laws better than others.

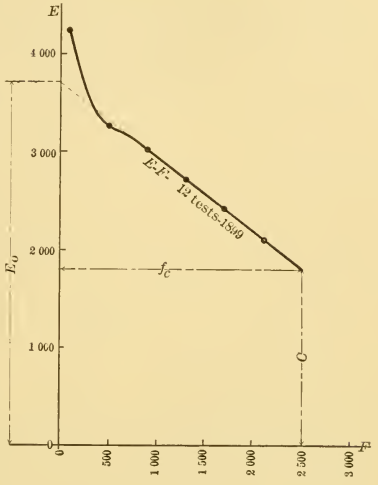

Fig. 2.

The unit for the *E* scale is, in all cases, 1 000 lb. per sq. in.; for the *F* scale, 1 lb. per sq. in.; for the *S* scale $\frac{1}{100\,000}$ of the unit of length.

The point of practical importance is the form of the stress-strain curve, such as *A–B*, Fig. 3. The three quantities, *E*, *F* and *S*, are necessarily related to each other, since $F = E\,S$. Any assumption made as to the

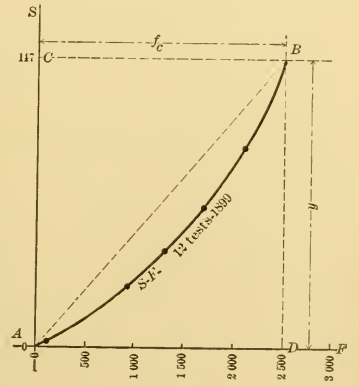

Fig. 3.

form of one of the curves given in Figs. 2 to 4 should not through this relation lead to results inconsistent with the forms found by experiment for the others. Suppose that the curve, *A–B*, of Fig. 3, is a parabola, with its vertex at *B*, and having its axis parallel to *A F*. Its equation will be

$$S^2 - 2\,y\,S = -\frac{y^2}{f_c}\,F \quad \ldots\ldots(1)$$

But $E\,S = F$ $\ldots\ldots(2)$

Eliminate F, and we get $E = \frac{2\,f_c}{y} - \frac{f_c}{y^2}\,S$ $\ldots\ldots(3)$

This is the equation of a right line, having an intercept of $\frac{2\,f_c}{y}$ for $S = 0$, and an ordinate equal to $\frac{f_c}{y}$ for $S = y$, *i. e.*, when the stress is equal to f_c. This assumption of a parabola, with vertex at *B*, therefore involves the assumption that *E* is a decreasing rectilinear function of *S*, reaching half of its initial value when the concrete fails. Examining the curve in Fig. 4, this assumption seems not so very far out of the way, though manifestly inaccurate.

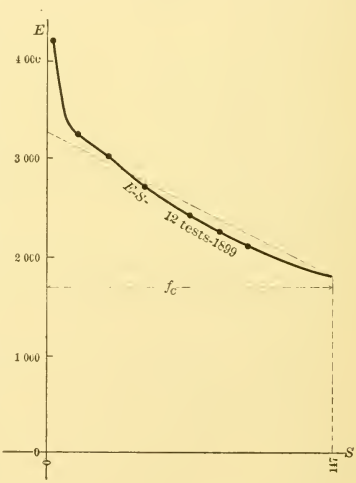

FIG. 4.

But now eliminate *S* from (1) and (2), and we get

$$E^2 - \frac{2\,f_c\,E}{y} = -\frac{f_c}{y^2}\,F \quad \ldots\ldots(4)$$

This is the equation of a parabola, situated with respect to the axes of co-ordinates in all respects similarly to the curve, *A–B*, of Fig. 3. By assuming the proper scales for plotting, the two curves could be made to coincide. For $F = 0$, there would be two values of *E*. Comparing this result with the *E–F* curve of Fig. 2,

it is seen that the result itself, and therefore the assumption which leads up to it, is absurd. In his early work in reinforced concrete, the writer, in common with many other engineers, made use of formulas based on this erroneous assumption.

Now assume that the curve, *A–B*, of Fig. 3, is a parabola, with its vertex at A, and its axis coincident with *A–S*. Its equation then will be

$$F^2 = \frac{f_c^2}{y} S \quad \ldots\ldots (5)$$

But $F = E\,S$. (Equation 2.)

Eliminate F, and we get $E^2 S = \frac{f_c^2}{y}$ $\ldots\ldots (6)$

This is a hyperbolic curve, and fits the *E–S* curve of Fig. 4 much more nearly than a straight line fits it.

Eliminate S, and we get,

$$F\,E = \frac{f_c^2}{y} \quad \ldots\ldots (7)$$

This is an equilateral hyperbola, and while it does not fit the *E–F* curve of Fig. 2 as well as a straight line, many *E–F* curves obtained from other tests show a decided similarity to a hyperbola.

The assumption of a parabola with its vertex at *A* (Fig. 3) is, therefore, much more accurate than the preceding assumption.

Assume now that the *E–F* curve of Fig. 2 is a right line, and that $E_o = 2\,C$. Its equation will then be

$$E = E_o - \frac{E_o}{2\,f_c} F \quad \ldots\ldots (8)$$

But $F = E\,S$. (Equation 2.)

Eliminate E, and we get

$$\frac{F}{S} = E_o - \frac{E_o}{2\,f_c} F \quad \ldots\ldots (9)$$

This is the equation of an equilateral hyperbola, passing through the origin of co-ordinates, and having, for asymptotes, the lines, $F = 2\,f_c$, and $S = -\frac{2\,f_c}{E_o}$. This curve seems to fit the actual line, *A–B*, of Fig. 3, better than any hitherto assumed.

Eliminate F, and we get,

$$\frac{E}{S} = \frac{E_o}{S} - \frac{E_o}{2\,f_c} E \quad \ldots\ldots (10)$$

This is also a hyperbola; it probably fits the E–S curve of Fig. 4 as well as any hitherto deduced, and better than a straight line. By determining the constants of the various curves above deduced, from the results of the tests, and then plotting them from their equations to proper scales, it would be possible to determine which really best fit the curves plotted directly from the tests. But this is not necessary, for practical purposes. It has been shown that the first assumption as to the form of the curve, A–B, of Fig. 2, leads to absurd results; this assumption also leads to the least thickness of concrete in actual designs. It is therefore safer to abandon it, and choose between the others.

The areas included between the axes of co-ordinates and curves such as A–B, of Fig. 3, plotted from actual tests, is a little more than 20% in excess of the area of the triangle, $A\ B\ C$. The center of gravity is a little nearer the line, A–F, than the center of gravity of the triangle. If A–B were a parabola, with its vertex at A, its included area would be $33\frac{1}{3}\%$ in excess of the triangular area, and the height of its center of gravity would be $\frac{3}{5}\ y$. The height of the center of gravity of the triangle is $\frac{2}{3}\ y$. The height of the center of gravity of the actual area is certainly between these limits. The triangular area is $\frac{1}{2}\ y\ f_c$. The parabolic area is $\frac{2}{3}\ y\ f_c$. It would seem that a very fair approximation to the truth would be attained by assuming the area included by the actual curve at $\frac{5}{8}\ y\ f_c$, and the height of its center of gravity at $\frac{3}{5}\ y$. Its moment about A would then be $\frac{3}{8}\ y^2\ f_c$. The moment for the parabolic area would be $\frac{2}{5}\ y^2\ f_c$ and for the triangular area, $\frac{1}{3}\ y^2\ f_c$. If A–B were a parabola, with its vertex at B, the moment would be $\frac{5}{12}\ y^2\ f_c$. The assumptions leading to a value for the moment of $\frac{3}{8}\ y^2\ f_c$ seem, therefore, to be a fair and conservative compromise between the extreme assumptions made by various engineers, and also to be sufficiently close to the truth. It is not necessary to have such heavy slabs as result from the assumption of a triangular area, nor is it safe to credit the concrete with so much work as is done in assuming a parabolic area, with the vertex of the curve at B. Conservative engineers in the United States generally neglect the resistance of the concrete in tension; upon the form of the stress-strain curve in compression, they are not agreed, but their assumptions are all found between the extreme limits above discussed. The writer now uses formulas based upon neglect of the concrete in tension, and a form for the stress-strain

curve giving a moment of $\frac{3}{8} p^2 f_c$, in the design of rectangular beams and slabs. These formulas are deduced on the assumption that the stress in the steel shall reach the elastic limit, when the stress in the concrete is about equal to the ultimate strength assumed for the grade of concrete used. The working load is multiplied by $2\frac{1}{2}$, and the beam or slab is designed to develop the extreme stresses under this multiplied load. Calculations based on experiments made with beams in which the strength of the steel was developed, indicate that, if designed on the above basis, the beam or slab would still be far from failure when the elastic limit of the steel and the assumed ultimate strength of the concrete are reached.

In addition to the section of maximum bending moment, however, the question of shear must be considered. The stress in the steel is practically proportional to the bending moment at different sections of the beam. The shear measures the rate of change of the moment, and therefore represents the rate of transfer of stress to the steel. Its value at the reactions is twice as great as its average value. It is therefore necessary to see that not only is there a sufficient area of contact between the steel and concrete to transmit the total stress in the steel, but also to see that the unit stress between the two materials and the longitudinal and vertical shear in the concrete near the reaction points do not exceed safe limits. Many beams have failed from neglect of this point. Another point worthy of consideration is that elongations in the steel, even within the elastic limit, diminish its cross-section; this must decrease the resistance to slipping near the middle of the span, and hence must throw additional stress upon the surfaces of contact near the reactions. Moreover, the shearing stress in the concrete gives rise to tensile stresses oblique to the axis of the piece. Many failures have occurred under these stresses, the beams cracking near the sections of maximum shear, along planes inclined about 45° to the horizontal and toward the center of the span. To prevent this method of failure, Hennebique introduced vertical stirrups and bent reinforcing rods. The writer has reason to believe that stirrups were used by Mr. E. L. Ransome, as early as 1891, for the same purpose. The opinion is gaining ground in America that, instead of vertical stirrups, oblique stirrups, inclined at an angle of 45°, away from the center

of the span, and attached to the horizontal reinforcement, are necessary for the best results. For rolling loads, the stirrups should be inclined both ways. Reinforcement of this sort, properly designed, will be just like the tensile members of a Pratt truss; the concrete will supply the compression members. The stirrups can be so proportioned and spaced that their adhesion in the concrete will develop the full strength of the horizontal reinforcement even though the latter is entirely beneath and outside of the concrete. The attachment between stirrup and bar must, of course, be equal in strength to the stirrup. The stirrups should reach practically to the upper surface of the concrete, and should be spaced closer together as the shear is greater; or else they should be stronger as the shear is greater, and the maximum spacing should in no case exceed the depth of the beam. Where stirrups are inclined both ways, they manifestly play the part, both of main braces, and counter-braces, in a Pratt truss. It would seem that a well-designed and well-executed beam or slab, reinforced in the way just described, could never fail without warning, and could always be depended upon to develop the strength of a larger percentage of steel reinforcement than a beam or slab without the attached stirrups. Another great advantage of the attached stirrups is that if, in a fire, the concrete flakes off and exposes the main bars, adequate repairs can be made by putting up a centering and calking new concrete in around the bars, for fire protection, pure and simple. Without attached stirrups, the new concrete would have to assist in transmitting stress between the steel and the rest of the slab, and this it could not do without an adequate bond with the old concrete. It would generally be necessary to tear the entire slab out and renew it, to make sure of the result. Unfortunately, the use of attached stirrups is covered by letters patent in this country, but this is a condition which will ultimately correct itself.

The structural advantages of attached stirrups become very marked in the case of beams of T-section, as these stirrups will transmit much of the stress directly into the flange, without calling into play the shearing strength of the concrete along the junction of stem and flange. This is often the weakest part of such beams.

But another plane of weakness in all beams, whether rectangular or T-shaped, is that through the horizontal reinforcing bars. In

T-beams especially, a heavy mass of metal is apt to be concentrated here, and the sectional area of concrete is much reduced; even if the resistance to slipping, when separately considered, is great enough to hold the steel, the longitudinal shearing strength of the concrete may be too small for the transmission of the stress to the steel. Attached stirrups will relieve the concrete surrounding the main bars of this duty, and leave it available for protection against fire and corrosion—not the least important of its functions.

In nearly all reinforced concrete work in this country, the thickness of concrete protecting the reinforcement from fire is quite inadequate. The minimum thickness for even very light reinforcement should not be less than 1 in., and for bars of any size, say from ½ in. up, it should not be less than 2½ in. Probably 4 in. would suffice for the very heaviest girders, in important work, but it should not be less. The advantages of attached stirrups in a fire are even greater for T-beams and girders than for rectangular beams or slabs, because of the greater exposure of the stem of the T to the disintegrating effect of the heat. In the Baltimore fire, enough reinforced concrete was exposed to demonstrate its value. It is not as good as structural steel covered with brickwork, but it is decidedly preferable to structural steel and the prevailing types of hollow-tile fireproofing.

T-beams generally occur in floor constructions of considerable span, where simple slabs would be too heavy, or where the shearing stresses around the columns would endanger a slab. The flange of the T is always a part of the floor slab. In its function as a slab, it is subject to compressive stresses in its upper part, at right angles to the rib; in its function as a flange, it is subject to compressive stresses, usually throughout its entire thickness, parallel to the rib. It is, therefore, subject to two systems of compressive stresses, at right angles to each other. So far as the writer knows, no formula in use at the present time takes account of this; he has never seen or heard, however, of a case of failure in practice, due to such compound stresses. Where, in addition to ribs running in one direction, as floor beams, there are other heavier ones at right angles to the beams, and acting as girders, a part of the floor slab in each case acts also as flange to the girder. As the reinforcement of the slab is parallel to the girder, the compressive stresses due to slab

and girder actions are in the same direction and superimposed. The writer knows of no formula that takes account of this condition, although it is more serious than the other. But neither has he ever heard of a failure in practice due to this summation of stresses. Several methods are available for lessening its evil effect—one is to make the floor slabs continuous over the beams, with reinforcement near the top to resist the reverse moment, and to space the beams so that there is always a beam at the central point of the girder. This will make the slab stresses of opposite sign from the girder stresses, where the latter are a maximum. Another plan would be to omit the ordinary reinforcement of the floor slab from the flange of the girder, and to substitute therefor reinforcement at right angles to the girder, near the top of the slab. This would cause the local floor loads to be carried directly by the girder, and the local stresses in the flange due to transmitting the load to the girder, would be at right angles to those induced by girder action. In any case, no formula could give the actual distribution of stresses in a ribbed concrete floor system with great accuracy; the case is too complicated. But it is possible to deduce formulas which will result in safe designs, when good judgment is used in providing against local stresses. In establishing such formulas it is important to determine how much of the floor slab may be depended upon to act with the beams and girders. So far as the writer is aware, the only engineer who has published formulas which determine this quantity from the conditions of the problem is A. L. Johnson, M. Am. Soc. C. E., Engineer of the St. Louis Expanded Metal Company. The formulas are published in one of the catalogues of that Company, and seem to the writer more rational and satisfactory than any others, except that Mr. Johnson takes account of the concrete in tension, which seems even less justifiable in T-beams than in rectangular ones. To the reasons given by M. Christophe for neglecting this element of strength, the writer would add only the following: If the steel is proportioned on the assumption that the concrete takes part of the tension, there will come a moment under increasing loads, near the elastic limit of the steel, when the concrete in tension will part and throw its load suddenly upon the steel; the stress in the steel will then greatly exceed the elastic limit, and a sudden collapse of the beam is possible; whereas, if the steel is

proportioned to take the entire tensile stress, this critical load may produce a sudden increase in the deflection, but will not probably cause a collapse. The writer has seen records of tests which seem to confirm the above statements.

In deducing formulas for T-beams, Mr. Johnson assumes that the stress-strain curve is a parabola, with its vertex on the neutral axis. This simplifies the formulas, and introduces no appreciable error, as the part of the parabola that lies outside of the true curve generally applies only to that part of the rib that is in compression; this is a very small percentage of the entire compressed portion. The part of the parabola that applies to the flange probably gives smaller values for the work of the concrete than would be given in the true curve, and thus leads to heavier and stronger designs. Mr. Johnson assumes that the stress is distributed, in any horizontal plane section of the flange, as the ordinates of a parabola, having its vertex at the point where the stress-strain curve is cut by the horizontal plane, and its axis coincident with the line of intersection of the horizontal plane with a vertical longitudinal plane through the middle of the rib. This assumption is not proved, but it is plausible and certainly seems safe. To determine the width of the rib, with reference to the thickness of the floor slab, the shearing strength of concrete is introduced, and allowance is made for the actual distribution of the shear. The resulting formulas are very simple; to apply them in designing, the thickness of the floor slab is determined from the conditions of the problem and the desired spacing of beams. The depth of the beam is assumed, and the other quantities follow. If the width of the flange is greater than the spacing of the beams, the problem has to be worked over. It is well so to assume the depth of the beam that the thickness of the floor slab will not be more than half of the distance from the extreme element in compression to the neutral axis; usually this is consistent with a design satisfactory in other respects, and it is economical, as tending to a more uniform distribution of stresses in the flange.

If, in either rectangular or T-beams, the compressed part is reinforced, the formulas can be easily modified to take account of the stresses in this reinforcement. Some American engineers have not, however, looked kindly upon reinforcing concrete against compres-

sion with longitudinal rods. They have preferred to make the section of concrete sufficient to take the compression, and to regard the reinforcement of compression members, especially columns, as provision against lateral flexure only. These views seem to be losing ground at this time, however, and reinforcement of the kind described is not in quite general use.

Reinforced concrete, especially where it includes the girders and beams, has been introduced in this country under many adverse conditions. Inspectors of buildings in municipalities, and many engineers, have demanded of it a factor of safety at least twice as great as that demanded of steel. This makes the cost prohibitive; if such a large factor of safety is really necessary, the material itself is unfit for resisting transverse strains at all. Many cases have occurred where a building inspector has demanded that large floor areas be loaded with six times the working load, including the weight of the construction itself. If the floor did not collapse, it was accepted, and allowed to stand! If it collapsed, the entire work was condemned! In other cases, an engineer has demanded that the floors of a building be designed with a factor of safety of four, based on the total dead and live loads, the elastic limit of the steel, and a very moderate assumed ultimate strength of concrete. The requirements, in both cases, were prohibitive; if justified by facts, it would mean that reinforced concrete is entirely unfit for such uses.

It is justifiable to demand of a new type of construction that it shall demonstrate repeatedly and on a large scale, that it has at least as high a factor of safety as that which it seeks to displace; but to demand of it a very much higher factor is unreasonable; it tends to encourage poor work, and is an indication that factors of safety in the prevailing types are too low, or that the new construction has defects that unfit it for any use at all.

The elastic limit of good medium steel in the United States is about 40 000 lb. per sq. in. The usual working stress in a building is 16 000 lb. per sq. in., so that the factor of safety, based on the elastic limit, is $2\frac{1}{2}$. There is little doubt that if the elastic limit in steel beams and girders is exceeded, the deflection would cause the collapse of nearly every form of floor arch or filling in common use in America; so that the factor of safety does not exceed $2\frac{1}{2}$, even though

the steel might hang together, after the stresses pass the elastic limit. But there is another point that is often overlooked; designs for steel-frame buildings may show excellent details; but the writer knows, from personal observation, that this excellence in design is largely nullified by indifferent and even criminally reckless work in the field, unless supervision is very close, and this is not often the case. Consequently, it is doubtful whether many of the modern steel-frame buildings would stand up if fully loaded, even up to the limit assumed for a safe working load. Fortunately, they almost never receive any such test. The inspection of erection work on a lofty steel frame is difficult, dangerous, and disagreeable; but the writer has done enough of it to know that if the riveting gangs could remember and would tell all that they know, many engineers who have turned out most excellent designs, but who have not had the opportunity to inspect the work in the field, would have many anxious moments. It is often claimed that the opportunities for poor work in reinforced concrete are unusually great; the writer cannot agree with this. One reasonably intelligent inspector at moderate wages can insure a proper mixture of concrete on a large work, especially if machine mixing be required. Another can insure the proper placing of the steel reinforcement. Against everything else, the concrete protects itself. The economy of reinforced concrete will much more than pay the cost of inspection.

A conservative figure for the compressive strength of good average concrete is 2 000 lb. per sq. in., at an age of, say, two months. As a low modulus of elasticity, other things being equal, leads to light designs, it is better to assume a fairly high value for the modulus. A study of the Watertown tests described above leads to the conclusion that E_o may be assumed at one-ninth of the modulus of steel, and E for $F = f_c$ at one-eighteenth of the modulus of steel. Using 40 000 lb. per sq. in. for the elastic limit of steel, and designing so that, according to the formulas, the stress in the extreme element of concrete will be 2 000 lb. per sq. in., and that in the steel, 40 000 lb. per sq. in. under a load of $2\frac{1}{2}$ times as great as the working load, including the weight of construction, will give beams, girders, etc., with a sufficient factor of safety for all ordinary purposes, provided the shear has been so provided for that the weakest section is at the point of maximum bending moment. Such beams and girders would not col-

lapse until the multiplied load was much exceeded, and they would give warning, by excessive deflection, in ample time to prevent a catastrophe. The load actually producing collapse would be almost certainly as much as four times the working load.

The use of reinforced concrete affords many opportunities for taking advantage of the principles of continuous girders. The material adapts itself to inequalities, and it is only necessary that the supports shall be practically unyielding. This is generally practicable; the continuity of structure gives great resistance to vibration, and enables a small overloaded area to call to its assistance surrounding parts in a way not possible with structures of the ordinary type. In detailing connections between the various elements of a design, and providing for local stresses, as much scope is given to the judgment and ingenuity of the engineer, as in the case of steel structures; so that reinforced concrete may justly claim the attention of all who desire strength, safety, permanence and economy combined in one structure.

Reinforced-concrete columns, in America, have generally been provided only with longitudinal bars. But a Canadian engineer, Mr. J. A. Jamieson, seems to have developed the hooped column independently, and without knowledge of the researches of M. Considère.* The inventor of the concrete piles used at Washington Barracks, D. C., has used metal lathing for reinforcing the concrete points of his piles against crushing, in much the same way, and probably without knowledge of M. Considère's experiments. So far as the writer knows, the manufacture of the members of a reinforced-concrete structure in the shop, with a view to assembling them after hardening, has never been attempted in this country, except for ceiling or floor slabs of moderate span, supported by rolled beams.

In actual construction work, centering is a large item of expense, and offers the best field for the exercise of ingenuity. For economical work, the design should consist of a repetition of identical units, and centering should be devised that will require a minimum of nailing to hold it and of labor to make and handle it. The cost of centering alone is often over 20% of the whole; a material reduction in this item would constitute, of itself, a handsome profit.

The writer appends his formulas for rectangular beams and his

* See *Engineering News* of June 23d, 1904.

modification of Mr. Johnson's formulas for T-beams. He claims no originality in either case—both sets of formulas are necessarily derived in the same way as existing ones, and differ only in the constants assumed. But as these constants are derived from a study of tests not hitherto used for this purpose, so far as the writer knows, the formulas may be of interest. In the case of rectangular beams or slabs of any importance, and in the case of all T-beams, attached stirrups capable of developing the full strength of the bars without assistance from the concrete immediately around the bars, are assumed. In addition, the usual asumptions as to plane sections, union of concrete and steel, absence of setting strains, etc., are understood; it is also assumed that the steel takes all the tensile stress, that the applied forces are vertical, and the beam horizontal.

Let E_s represent the modulus of elasticity of steel;

E_c represent the modulus of elasticity of concrete;

T represent the unit tensile stress in the steel;

t_s represent the elastic limit of steel;

F represent the unit compressive stress in the concrete;

f_c represent the ultimate compressive strength of concrete per unit of area; all in pounds per square inch.

RECTANGULAR BEAMS

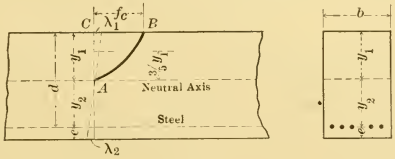

FIG. 5.

Referring to Fig. 5,

Let b represent the width of the beam, in inches;

a represent the sectional area of steel per inch of width;

ab represent the total sectional area of steel in the beam;

y_1 represent the distance of the neutral axis from extreme element in compression;

y_2 represent the distance of the neutral axis from center of gravity of steel reinforcement;

λ_1 represent the compression in the extreme element of concrete, per unit of length;

λ_2 represent the elongation in the steel, per unit of length;

$A\ B$, Fig. 5, represent the stress-strain curve, such that the area, $A\ B\ C$, is $\frac{5}{8} f_c\ y_1$, and its lever arm with respect to A is $\frac{3}{5}\ y_1$, when F for the extreme element of concrete in compression is equal to f_c, and when T is at or below the elastic limit of the steel.

Then,

$$y_1 + y_2 = d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{\lambda_2}{\lambda_1} = \frac{y_2}{y_1}, \quad \lambda_1 = \frac{F}{E_c} \quad \text{and} \quad \lambda_2 = \frac{T}{E_s}$$

Therefore,

$$\frac{y_2}{y_1} = \frac{T\ E_c}{F\ E_s}, \text{ and } y_2 = \frac{T\ E_c}{F\ E_s}\ y_1 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Therefore,

$$y_2 = \frac{t_s}{f_c}\frac{E_c}{E_s}\ y_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2a)$$

Equation 2 applies as long as F does not exceed f_c and T does not exceed the elastic limit; but the values of F and E_c must always be those that correspond to each other.

When $F = f_c$, and T is equal to the elastic limit, the conditions of equilibrium give,

$$\frac{5}{8}\ b\ y_1 f_c = a\ b\ t_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

If M represent the maximum bending moment due to the applied forces, in inch-pounds,

$$M = \frac{3}{8}\ b\ y_1^2 f_c + a\ b\ t_s\ y_2 \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

In designing, substitute proper values for f_c, t_s, E_s and E_c, according to the quality of materials to be used.

Substitute the value of M from the conditions of loading (safe load $\times$ $2\frac{1}{2}$); then y_1 can be determined, and from it, all the other quantities. ϵ (see Fig. 5) should never be less than 1 in. + $\frac{1}{2}$ diameter of bars; nor less than 6 diameters in any case, until it reaches a maximum of 4 in. This is for fire protection.

In testing a given design, d, M, E_s, and E_c are known. f_c and t_s may be determined, but they will only be approximately correct, unless they are actually near the ultimate strength of concrete and the elastic limit of steel, respectively. If they fall far short of these values, it is better to assume for the area coefficient of the stress-strain curve, eleven-twentieths instead of five-eighths, and to try different values of E_c, until a consistent value for F is found: this and the resulting value of T will be fairly accurate.

T-Beams.

The assumptions are: Plane sections, unity of action of concrete and steel, no initial stresses due to setting strains, loads vertical, beam horizontal, steel takes all tensile stress. The stress-strain curve is a parabola, with vertex on neutral axis, as A, Fig 6. Let the dimensions of the sections be denoted by the letters in the figure, all being expressed in inches. Assume that the center of gravity of the area, $B\ C\ G\ H$, is at the center of the flange thickness, so that its lever arm with respect to A is $y_3 + \frac{t}{2}$. This is slightly in error, on the safe side. Assume that in any horizontal plane, the compression flange stresses vary as the ordinates of a parabolic segment, having its vertex where its plane cuts the curve $A\ B$, and its axis coincident with the line of intersection of its plane, and a longitudinal vertical plane through the middle of the rib; the maximum ordinate of the segment being at the vertex, and equal to the F ordinate of the curve $A\ B$ at the same point; its ordinates at the edges of the flange reducing to 0.

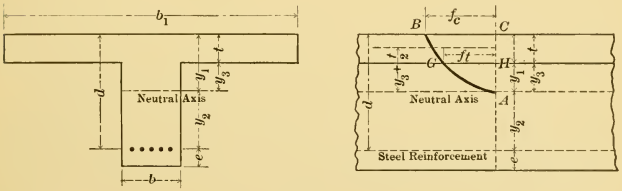

Fig. 6.

Let P_c represent the total compressive stress in the concrete;

P_c' represent the total compressive stress in the stem of the T;

P_c'' represent the total compressive stress in the flange of the T;

P_s represent the total tensile stress in the steel;

L represent the length of the span, in feet;

s represent the shearing strength of concrete in pounds per square inch;

S_h represent the total shear between rib and flange, along their plane of union;

S_v represent the total shear in the flange along vertical planes cutting off the wings of the flange.

Assume other quantities, as in the case of rectangular beams: Equations 1 and 2 under rectangular beams apply here also. Therefore,

$$y_1 + y_2 = d \text{ (Equation 1).}$$

$$y_2 = \frac{T E_c}{F E_s} y_1 \text{ (Equation 2), and } y_2 = \frac{t_s E_c}{f_c E_s} y_1 \text{ (Equation 2 } a\text{).}$$

From the assumptions made for T-beams, and the conditions of equilibrium,

$P_c = P_c' + P_c'' = P_s = a\, b\, T$ (Equation 3).

Therefore,

$$a\, b = \frac{P_c}{T} = \frac{P_s}{T} \text{ (Equation 4); or, } a\, b = \frac{P_c}{t_s} = \frac{P_s}{t_s} \text{ (Equation 4 } a\text{).}$$

From Johnson's Equation 6, in his "Materials of Construction," p. 29, $s = \frac{f_c}{2 \text{ tan. } \theta}$, in which θ is the angle of rupture under direct compressive stress. It is usually about 60°, whence $s = \frac{f_c}{3.464}$; but it is thought best to assume, for safety, $s = \frac{f_c}{8}$. $P_c'' = S_h = S_v$ (not strictly true for S_v, as a part of P_c'' is not transmitted to the wings; the error is on the safe side).

$S_h = \frac{1}{2}\, s \times b \times \frac{1}{2}\, L \times 12 = 3\, b\, s\, L.$

$S_v = \frac{1}{2}\, s \times 2\, t \times \frac{1}{2}\, L \times 12 = 6\, t\, s\, L.$

It is evident that, for equal strength in shear, b should be at least twice as great as t, and t practically equal to $\frac{1}{2}\, b$.

The equation of the stress-strain curve, referred to A as the origin of co-ordinates is, $F^2 = \frac{f_c^2}{y_1}\, y$.

Hence, $f_t = \left(\frac{f_c^2}{y_1}\, y_3\right)^{\frac{1}{2}}$.

Therefore, $P_c' = \frac{2}{3}\, y_3 \left(\frac{f_c^2}{y_1}\, y_3\right)^{\frac{1}{2}} b = \frac{2}{3}\, b f_c'\, y_1 \left(\frac{y_3}{y_1}\right)^{\frac{3}{2}}$ .....(5)

From the equation of the stress-strain curve, and the properties of the horizontal parabola assumed as the curve of stress in the flange, we have,

$$P_c'' = \tfrac{2}{3}\, b_1 \left(\tfrac{2}{3} f_c\, y_1 - \tfrac{2}{3} f_c\, y_1 \left(\frac{y_3}{y_1} \right)^{\frac{3}{2}} \right) =$$

$$\tfrac{4}{9}\, b_1 f_c\, y_1 \left(1 - \left(\frac{y_3}{y_1} \right)^{\frac{3}{2}} \right) \quad \ldots\ldots\ldots\ldots (6)$$

$$S_h = 3\, b\, s\, L = P_c'' = \tfrac{4}{9}\, b_1\, f_c\, y_1 \left(1 - \left(\frac{y_3}{y_1} \right)^{\frac{3}{2}} \right).$$

$s = \dfrac{f_c}{S}$, hence,

$$\tfrac{3}{8}\, b\, f_c\, L = \tfrac{4}{9}\, b_1 f_c\, y_1 \left(1 - \left(\frac{y_3}{y_1} \right)^{\frac{3}{2}} \right).$$

Therefore, $b_1 = \dfrac{27}{32} \dfrac{b\, L}{y_1 \left(1 - \left(\dfrac{y_3}{y_1} \right)^{\frac{3}{2}} \right)} \quad \ldots\ldots\ldots\ldots (7)$

Substituting this value in Equation 6, we get,

$$P_c'' = \tfrac{3}{8} f_c\, b\, L \quad \ldots\ldots\ldots\ldots (8)$$

$$P_c = P_c' + P_c'' = \tfrac{3}{8}\, b f_c\, L + \tfrac{2}{3}\, b f_c\, y_1 \left(\frac{y_3}{y_1} \right)^{\frac{3}{2}}$$

$$= b f_c \left(\tfrac{3}{8} L + \tfrac{2}{3}\, y_1 \left(\frac{y_3}{y_1} \right)^{\frac{3}{2}} \right).$$

$$M = \tfrac{3}{5}\, y_3\, P_c' + \left(y_3 + \frac{t}{2} \right) P_c'' + P_s\, y_2 \quad \ldots\ldots\ldots\ldots (9)$$

The numbered equations are sufficient for designing.

Determine t from the requirements of the floor slab; assume d (if possible, so that d will be at least $= 4\, t$). Compute P_c', P_c'', and P_s—all in terms of b. Substitute in Equation 9, and b may be determined. If $b > 2\, t$, t must be increased; in designing T-beams, as in rectangular beams, compute M for a load $2\frac{1}{2}$ times greater than the working load. Make $F = f_c$, and $T = t_s$.

It will be found that, for similar assumptions as to the relative values of d and t and the same values of f_c and E_c, designs of similar cross-section will be obtained for different loads and spans, so that the moment of the stresses may be written, quite accurately, in the form, $M = k f_c\, t\, b_1 \left(y_2 + y_3 + \dfrac{t}{2} \right)$.

It will also be found that b_1 will be practically equal to b, multiplied by a constant. This enables a design of a certain type to be detailed quite simply and quickly, and also gives a means of quickly determining the approximate stresses in a given design, after the constant k and the ratio of b_1 to b have been determined for various types of designs, *i. e.*, for various groups of assumptions as to the

values of f_c, and E_c, combined with the various values of t, corresponding to different spans and loadings.

The quantity, e, in Fig. 6, should be determined as for rectangular beams, and it should be the minimum thickness of concrete protecting the steel, laterally, as well as vertically.

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Paper No. 72.

CONCRETE AND CONCRETE-STEEL.

CONCRETE AND CONCRETE-STEEL IN FRANCE.

By A. Considère.*

Translated from the French by
Paul A. Seurot, M. Am. Soc. C. E.

It was about 1893 that the first important application of reinforced concrete, of which Monier appears to have had the first conception, was made in France. Since that time this new style of construction has been extensively used and its adoption seems destined to become still more general.

Materials Used.

Cement.—Portland cement and other slow-setting cements are generally used in reinforced constructions. Lime is also used in the parts where the resistance or strength may be less, and quick-setting cements are used in the construction of pipes.

Proportions of Sand and Gravel.—Although silicious sands and gravels are preferable, those of calcareous nature may be used when the former are not available.

The mixing is done in proportions varying as the sizes of the

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particles, and in order to reduce the voids to a minimum. In buildings, the usual practice is to add 300 kg. of cement to a total volume of 1.2 cu. m. of sand and gravel mixed, and it is assumed that, after losses at the mixing pans and after ramming, there is 1 cu. m. of concrete measured in place. In submarine works, the proportion of cement is increased to 500 or 550 kg. per cu. m., measured in place.

Water Used in Mixing Concrete.—Contractors, as a rule, use a concrete which is just moist enough to flow between the reinforcing members and coat them with cement, but, at the same time, is able to stand ramming.

Some have advised the use of very wet concrete in moulds and forms perforated with holes through which the excess water can be drained; but several experiments have shown that the concrete thus made is greatly inferior as to its resistance and coefficient of elasticity.

Metal.—The cheapest quality of steel, having a strength of 40 to 45 kg. and an elongation of 20 to 26%, is generally used.

Arrangement of Principal Members.

Members in Tension.

Until recently, the reinforced concrete was subject to tension in deflected members only. Lately, M. Vizentini used it in lattice girders, and the writer has used it in the construction of the chords and web members of the bow-string truss bridge tested to destruction at Ivry-Paris in November, 1903. In both cases, the aim has been to give to the metal bars the same length as the members they reinforced, and in doing so, it was possible to obtain members which did not present sections of smaller resistance, such as are found in riveted members.

Members in Compression.

In France the practice is to reinforce compressed members with longitudinal bars or rods, connected at certain intervals by perforated diaphragms or by wires. In all calculations, the transverse ties are neglected, and the resistance of the metal is supposed to be added to the resistance of the concrete.

The upper chords of the Ivry Bridge were designed differently. Helicoidal spiral rods were bedded in concrete near the surface, and against the inner face of these coils reinforcing longitudinal rods were placed. Several experiments and the Ivry test have proved that the spiral rods or hoops give to the core of concrete gripped within them a greater crushing strength—2.4 times greater —than the strength of longitudinal reinforcing members of the same weight.

Moreover, hooped concrete becomes about 20 times more ductile than concrete reinforced longitudinally, and, therefore, gives more surely and more completely the proper resistance of which it is capable, notwithstanding settlements of the abutments or the effects of expansion.

Slabs and Beams Subject to Flexure.

Designers have endeavored to invent special arrangements, the description of which would be too long; only their essential differences will be mentioned herein.

Longitudinal Reinforcements.—Leaving out of consideration reinforcements latticed in some more or less rational way and skeletons built up of standard shapes and riveted members, the use of which has only a secondary importance in France, it may be said that, generally, the longitudinal reinforcements consist of round rods with smooth surfaces, and that the adhesion of the concrete is assumed to be sufficient to prevent slipping. Experiments have shown that such is generally the case under two conditions: good workmanship, and a relatively low ratio between the diameter of the rods and the span of the beams. It must not be concluded from this that bars with rough surfaces or with corrugations will not be useful, nor that the method of tying the longitudinal rods by transverse stirrups, as is done in foreign countries, could not be utilized.

Some designers have only reinforced along their whole length the lower fibers of members subjected to flexure, without trying to insure the resistance to tension of the upper fibers, above the supports, where bending moments of opposite direction to those existing at the middle of the span are developed. With this faulty disposition, serious breaks, not admissible in good construction, occur above the supports.

There are two rational types:

1.—In continuous beams the lower reinforcing members are generally carried throughout the entire length of the beams, and, in addition to these, upper reinforcing members are placed above the intermediate supports, the duty of which is to resist the negative bending moments.

The upper reinforcing members are extended throughout the entire length of the beams when the concrete has not strength enough to resist all the strains, or simply when it is found convenient to do so in order to fix the transverse ties.

2.—In the second type, recommended and used by M. Hennebique, only one-half of the lower bars extend horizontally for the entire length of the beams. The other half is found only at the center of the beams, along about one-third of their length and rise, at both ends, at such an angle as to reinforce properly the upper fibers above the supports. Besides the advantage of reinforcing the concrete, wherever it is subject to tension, without the help of additional rods, the bars so bent effectively resist all shearing stresses near the supports, where they are the greatest. On the other hand, this arrangement tends to lessen the compressive strength of the beams on the supports, which in certain cases may be detrimental. It is well also to note that the bars so bent are subject to tensile stresses along their entire length, and that, therefore, they tend to pull their extremities with all this concentrated effort, whereas straight bars are held by the adhesion distributed upon their whole length, and exert no pull, or very little, at their extremities.

To these few remarks, which refer alike to all deflected pieces, it is well to add a few words in reference to arches or floors.

Arches or floors carrying loads are generally reinforced only in a direction perpendicular to the direction of the beams. On the contrary, floors, such as street or bridge floors, which must carry heavy concentrated loads, are reinforced in two directions, perpendicular to each other. They are often divided into squares or slabs supported by two series of beams forming a grillage.

Transverse Reinforcements.—These reinforcements, the duty of which is to resist all shearing stresses, can be divided into three types:

1.—Vertical reinforcements, composed of flat or round iron wound in the shape of stirrups around the lower reinforcing bars;

2.—Bars alternately inclined at 45° in two directions, as the diagonal members of a bridge truss;

3.—Bars inclined at 45° but in one direction only, ascending from the center toward the supports, that is, in the direction where the shear produces tension.

Theoretically, the last type is the most rational, but it is little used owing to the difficulty of keeping these inclined members in position during the concreting, when, after all, it is necessary to fasten their upper ends to horizontal metal bars generally doing no work whatever.

The second type adds to this trouble another, and that is the introduction of useless reinforcing members in the direction of the compression, which is easily resisted by the concrete.

In fact, vertical stirrups are used in France almost exclusively.

Calculation of the Bending Moments and Shears.

In all armored or reinforced construction, this calculation is particularly difficult, owing to the fact that the component parts have become dependent upon one another, losing their identity in the whole. This solidarity of the component parts manifests itself in three distinct ways.

Longitudinal Continuity.—Floors, beams and girders are nearly always continuous over the supports. If they had everywhere an equal resistance to flexure, the stresses could be determined by the usual formulas for calculations of strength of materials; in other words, if a were the common length of the spans and p the uniformly distributed load per meter, the bending moment would be $\frac{1}{12} pa^2$ on supports and $\frac{1}{24} pa^2$ at the middle of the spans. But, in most constructions, the load bears only upon certain spans, and therefore the moment at a support may be much lower than $\frac{1}{12} pa^2$, whatever be the construction of the pieces, and the moment at the center of the span may be much higher than $\frac{1}{24} pa^2$, so that the safety would be endangered in certain cases if the stresses were calculated by the above formulas. This is the reason why French

designers assume that the safe minimum of the moment on the supports is only $\frac{1}{10}\ pa^2$, so that the resistance at the center must be based upon a bending moment of $\frac{1}{10}\ pa^2$. It is known that the moment would be $\frac{1}{8}\ pa^2$, if the fact that the beam is built in or fixed at both ends were neglected.

Distribution of Concentrated Loads Between Parallel Members.—This distribution depends evidently upon the relative values of the floors, slabs, or arches, of the beams and of the girders, and no general rule can be given. However, it is interesting to note that in the experiments made by the Commission for the study of reinforced concrete appointed by the Minister of Public Works in France, it has been discovered under various circumstances that the fatigue of beams or girders supporting concentrated loads was less than half what it should have been, were it not for the solidarity of similar and parallel members.

Width of Arches or Floors Strained by Concentrated Loads.—The Commission made no experiments in this instance. It is evident that the area of a floor containing two series of reinforcements perpendicular to each other, and strained—that is, under the influence of a load—depends upon the thickness of the concrete and the size of the reinforcements. For floors under roadways, having a thickness of 12 to 16 cm., it is generally admitted that concentrated loads can be uniformly distributed on a width of 1 m.

Participation of the Arches and Floors in the Deflections of the Beams.—The experiments of the French Commission were not made upon a sufficiently large number of constructions to permit final figures to be obtained; but, nevertheless, their results, condensed farther on, give, perhaps, the most desirable and profitable data for the calculations. Very narrow floors or arches may be considered as being intimately united to and forming parts of the beams. The coefficient of participation is still 0.90 when the ratio of the spacing of the beams to their span is equal to 0.40, so that the width of the floor thoroughly conforming to the deformations of the beam is $0.90 \times 0.40 = 0.36$ of the span of the beams. If the spacing of beams increases beyond this limit, the effective work done by the floor does not increase much, and the equivalent width of floor does not seem to go beyond 0.40 of the span of the beams.

Calculations of the Sizes and Deformations of Reinforced Beams.

Formulas More Generally Used.

In calculating dimensions, M. Hennebique uses an empirical rule, which deserves a great deal of attention, owing to the very large number of constructions in which it has been successfully used. But some engineers who do not believe in using methods at variance with incontestable scientific principles, do not accept it because it is based upon the hypothesis of the inequality of the two opposite components of the couples of flexure. In practice, the result of the empirical formula mentioned above is to give, for tension and for parts subject to tensile stresses, values from 5 to 20% lower than those found with the other formulas.

It appears that M. Coignet was the first to publish in France a theoretical study of the strength of armored concrete, in which he applied to the calculations of bending stresses the hypothesis of the conservation of plane sections, which serves as the basis of the science and study of the strength of materials. He has neglected the tension in the concrete because it does not appear in fissures.

M. Christophe has taken up the same hypothesis in his important treatise, "Le Béton Armé et ses Applications" (Armored Concrete and Its Applications). He has corrected an error pertinent to the position of the resultant of pressures, and has taken 10 as the ratio of the coefficient of elasticity of metal and concrete. He very ably deduced from these hypotheses formulas which apply to the various problems the designer has to solve.

Results Obtained and Consequences.

The writer thought advisable to study the properties of armored concrete, and, first of all, the effects of setting in relation to the volume; that is, its contraction, the internal stresses developed, and the production of fissures or cracks.

Afterward, he found that armored concrete when intact, or the concrete of blocks or portions separated by fissures, can withstand greater elongations than those which break ordinary unarmored concrete, and that, in these supplementary deformations, the coefficient of elasticity of the concrete is practically nothing.

He proved that the hypothesis of conservation of plane sections, although wrong in itself, gave results accurate enough to calculate all bending moments, except in the immediate vicinity of heavy concentrated loads.

In order to draw from these facts conclusions referring to the calculation of armored constructions, it is enough to recall the well-known fact that the coefficient of elasticity of concrete under compression decreases very much before rupture happens, especially in deflected beams where there is, before rupture, a decided shortening. This must be borne in mind in all calculations of resisting moments and breaking loads, and, consequently, of safe working loads proportional to this resistance or strength.

From this the following conclusions can be drawn:

Longitudinal Reinforcements and Concrete.—For preliminary calculations or deductions following the deformations, it is necessary to take into account the tensile stresses of the reinforced concrete, and the nullification of its coefficient of elasticity beyond the elastic limit.

For calculating the sizes, there is an added factor of safety in neglecting not only the uncertain help given by the tensile strength of the concrete to the resistance or strength of the reinforcing members, but also the fact that the neutral axis has been lowered, as a certain consequence of the tensions developed even in fissured concrete. One is thus compelled to adopt M. Christophe's formulas by giving to the ratio of the coefficients of elasticity a value equal to 15 or even 20, instead of 10, in order to take into account the diminution of the coefficient of elasticity of concrete compressed before rupture.

Transverse Reinforcements.—Some designers assume that the transverse or inclined reinforcements ought to resist alone the sum of all shearing stresses. Others think that for floors, slabs, or flat arches, almost invariably poorly reinforced, and resisting, in consequence, only low shearing strains, concrete and the longitudinal reinforcements are sufficient to take care of these strains without the additional help of stirrups. On the contrary, all designers seem to be of one accord in reinforcing transversely all beams, because the concrete filling does not always adhere to the floor girders.

Applications of Armored Concrete.

These applications are as numerous as varied, and the writer can give here only a very incomplete enumeration.

Foundations and Retaining Walls.—Large slabs built of reinforced concrete and subject to flexure, are well adapted to constructions in which it is desirable to distribute the superincumbent loads upon large areas on poor soils. In this instance must be mentioned the repairs made by M. Hennebique in 1896, on the steeple of the Church of Notre-Dame de Brebières at Albert (Somme), which weighed 8 870 tons and had settled 13 cm. in 5 days.

For retaining walls, and particularly the wall built along the Debilly Quay during the Paris International Exposition of 1900, the same designer adopted a very economical solution, consisting in connecting, by means of buttresses, the face of the wall itself to a lower platform or footing, which made the center of the foundation coincide with the center of the pressures; and midway between the top and bottom of the wall, an interior platform, loaded by an earth fill, the duty of which is to resist the overturning moment.

Pile-Foundations, Trestles, Piers.—Wood is replaced by reinforced concrete in pile-foundations and in the construction of piers. As instances, may be mentioned the jetty of Arcachon, the quays of Nantes, the cantilever construction in the trestle of the Nantes mills measuring 9 m. in width, and the landings at Cherbourg.

Reinforced concrete was also used in slabs in shafts connecting the caissons sunk by compressed air in the Pinède Basin at Marseilles.

Buildings.—The fire-proof properties of reinforced concrete and its cheapness have led to its adoption in the construction of all parts of buildings: foundations, columns, floors, balconies, front walls, partitions, roofs, stairs, etc.

The applications made in the buildings of the Exposition of 1900 are too well known to be recalled here.

Vaults, Reservoirs, Tanks.—In these constructions, armored concrete is used for the walls which are reinforced at certain intervals.

Water Pipes.—The most important applications have been made in the municipal service of Paris under the direction of M. Bechmann, Chief Engineer, with the assistance of M. Launay.

At the present time, the mains in operation have a length of 170 km. and diameters ranging from 0.30 m. to 2 m. These have proved very successful, and when it became necessary to take up some pipes, it was found that the concrete was intact, and that the reinforcing bars, when scraped free from the rust that covered them before they were used, were perfectly clean and bright. These pipes are of two distinct types.

When the pressure is not higher than 33 m., the pressure reached in the Méry-Pierrelaye main, all that is done is to reinforce the concrete with hoops made of T's connected by a few longitudinal ties.

Pipes built according to the Bonna system have been tested up to a pressure of 118 m., and used under a pressure of 55 m. They consist of a core of sheet metal leaded and bedded between two concrete cylinders, reinforced with metal members crossing one another (iron mesh).

Recently M. Bonna, in order to be able to use tin soldering, has substituted for leaded sheets, ordinary sheets which are cemented by autogenous soldering made with an oxyhydrogen blow-pipe or with a mixture of oxygen and acetylene under pressure.

Lately, cemented joints have been superseded by joints made with a bituminous mastic, which hardens very rapidly, and permits the use of repaired pipes within 24 hours.

Bridges.—A great number of bridges with straight chords, ranging from 8 to 15 m. in span, have been built according to the methods adopted in constructing the floors of buildings. But the longest girder built in France, and which has a span of 20.6 m. and a depth of 1.45 m., was designed by M. Hennebique to support the stage wall of the Moulin Rouge at Paris, and which is able to support, it is said, 989 000 kg.

Several arched bridges have been built, the most important one being the Chatellerault Bridge, which consists of three arches with spans measuring 40, 50 and 40 m., respectively, with a ratio of 1 to 10 between the rise and the span.

While, in Germany, engineers hinge their arches in order to avoid the effects of expansion and contraction due to settlement, French engineers, and particularly M. Hennebique, in his Chatellerault Bridge, make all parts of their bridges perfectly rigid and

dependent on one another, claiming that the strength and resistance are proportionately increased. It is too early yet to draw final conclusions, but it is well to point out incontestable facts, and to note that the concrete floor, the longitudinal chords, and the shortest vertical posts of the Chatellerault Bridge are streaked wholly or partly by cracks and fissures much wider than any fissures generally seen in armored constructions. It is possible that with some precautions such fissures may be avoided or corrected. The Ivry test-bridge, mentioned before, introduces a new type. It need only be stated that, during the test, the hooped concrete supported, without rupture, a pressure of 434 kg. per sq. cm. of total cross-section, and that in the breaking test made afterward upon sections cut out from this work, there was a pressure of 537 kg.

Works Constructed by M. Rabut.—Chief Engineer Rabut has designed several works, especially on the Courcelles-Passy Railroad: roofs of tunnels, footbridges, platforms supporting heavy railroad stations, cantilever sidewalks, and sewers. His methods of construction are somewhat similar to the best-known types; but what is worth mentioning in M. Rabut's work is the fact, brought to light by several records of measures of deformation, that all the parts of an armored construction are remarkably dependent on one another, that they act, so to speak, together, as a unit, as a whole, much more so than in any metallic construction.

M. Rabut has taken advantage of this fact in his calculations, which have been crowned with the greatest success. He has also shown the increase in strength and rigidity given to metal constructions by either connecting their chords or beams to the reinforced concrete floor, or by bedding them in longitudinal brick arches carrying above a fill of cement concrete.

Works Executed by M. Harel De La Noé.—Besides making some interesting applications of the usual types of reinforced concrete, Chief Engineer Harel de la Noé has executed some works in which the reinforced concrete is combined with the masonry and the metal constructions under new conditions.

Viaduct piers of extraordinary lightness have been built of ordinary masonry having a double T section with a web thickness of 0.5 m. and a thickness of from 0.5 to 0.7 m. for the wings, according as the height was below or above 15 m.

This type of construction, which has carried loads six times greater than any to which they might actually be subjected, has been possible only by using slabs or slices of reinforced concrete 0.10 m. in thickness, spaced 2 m. apart, and traversing the section in its entirety; these blocks have distributed the pressures and prevented breaks and cracks.

The arches supported by these piers have spans of from 6 to 7 m., and are made up of masonry rings of 0.80 m. to 1 m. in width, and spaced from 2 to 3.5 m. apart, center to center; their extrados supports reinforced concrete slabs the thickness of which is one-tenth their clear span.

M. Harel de la Noé has also made new applications of reinforced concrete in separation walls, 50 cm. thick, and forming the essential parts of retaining walls having a height of 12 m.; and also in the fenders of piers of a bridge, the span of which measured 90 m.

Moreover, this engineer has published several papers, on the theory of reinforced concrete, which cannot be analyzed here.

Several other engineers and builders have taken the greatest interest in the improvement of reinforced concrete construction in France. It is to be regretted that the lack of space in this paper prevents more than mentioning this fact.

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Paper No. 73.

CONCRETE AND CONCRETE-STEEL.

CONCRETE AND CONCRETE-STEEL IN HOLLAND.

By J. J. L. Bourdrer.*

It would be difficult to draw the chronological line of demarcation between armed concrete as a material for the fabrication of sundry smaller objects of domestic technical use, and armed concrete as a building material; between the progeny of Monier's aboriginal flower-pot and the floor-slabs that grew into whole buildings, the pillars that developed into piers and quay walls and into engineering work of bold conception.

It is certain that before 1893 no "Monier work" of importance had been made in Holland. It is curious to note that whatever there was—water and sewerage pipes, cisterns, tanks, etc.—seemed to have been made on purpose to brave the sentence of condemnation—passed upon all Monier work by the judges of the day—due to rust. The first really important work, built in Holland in 1893, was of this nature. This was an underground water conduit for a sluice underneath the embankment of the River Maas near Heusden. It had a length of 22 m., a width of a little more than 3 m. Its cross-section was rectangular at the bottom and circular at the top. The concrete at the top was only 5 in. (0.13 m.) thick; the iron skeleton

*Civil engineer and architect.

consisted of bars varying in diameter from $\frac{1}{4}$ to $\frac{3}{8}$ in., embedded crosswise in the concrete, which consisted of 1 part of cement to 1 of gravel and 2 of sharp sand. This undertaking, a daring one ten years ago, was due to the initiative of R. T. J. Tutein-Nolthenius, M. Am. Soc. C. E., then Royal Engineer at 's Hertogenbosch. The canal is in perfect condition at this moment, and proves, at all events, that the process of demolition by rust is a very slow one. It was built by a German company, the Berlin Actien Gesellschaft für Monier Bauten.

In the following year, 1894, a similar work was carried out by a Dutch firm called the Amsterdam Monier Company. This was a sort of tunnel passing under the public road in front of the Wilhelmina Hospital at Amsterdam. From an engineering point of view it was even a less important work than the before-mentioned sluice canal. It was 5 ft. wide and about 1 yd. high; the thickness of the concrete being nowhere more than $1\frac{1}{2}$ in. But it is noteworthy because it shows that in 1894 Monier work began to develop as a national industry. Two years later the same firm covered an area of some 365 sq. m. with a flooring of armed concrete supported by rafters spanning 5.48 m. Although this work bore a semi-official character, it being the Private Record Office of Her Majesty the Queen, at The Hague, in which the floor was laid, it cannot be said that these constructions became popular, although their advantage in such a case as this, where all danger of fire should be excluded, were incontestable.

During the closing years of the nineteenth century there is virtually a blank in the history of armed concrete nearly everywhere, except in France; and if the impulse at the beginning of a new era was vigorous, it was without question through the influence of Hennebique. The fact that he contrived to raise the number of works executed under his guidance from a paltry dozen in 1892 to more than a thousand (some of which are in Holland) in 1900 could not fail to attract the attention, which means the favour, of the public. Periodicals published descriptive and critical papers on the subject. The Belgian Royal Engineer, Christophe, was the first to publish his views on the scientific side of the question.

The scope of this account prevents the writer from venturing upon even a mere epitome of the theories built up, which would

require a paper for itself. It will be agreed that, the material being heterogeneous, a correct theory cannot be built on this incorrect basis. The method, therefore, of calculating constructions of this kind is, and always will be, the shrewd application of the accepted rule derived from the laws of elasticity, but brought to bear, by the aid of an ingenious hypothesis, upon the juxtaposition of different materials.

Since 1900, not only floors, basins, and pillars have been constructed, but the Government, the Board of Works of Rotterdam, several railway and other great companies, have planned and carried out works of great interest from an engineering point of view, such as bridges, viaducts, quay walls and buildings. It is impossible to arrange a list of these works chronologically, as they are nearly coincident, and it will therefore answer the purpose best to give a categorical notice of them in their amazing variety, to dwell upon such as open a new perspective, and to illustrate in this way the rapid progress, toward popularity and widespread application, of this new material.

It is to be regretted that foundations cannot open the pageant more brilliantly, as they would have been characteristic of Holland. It is the more to be regretted as there was every reason to expect, from what was actually attempted, that this new departure in subterraneous or submarine engineering would have produced startling results. In 1900 the Holland-American Steamship Company built a large depot alongside its landing-stage at Rotterdam. The nature of the soil was peculiar. It could not be said to represent the standard type in the provinces of Holland, which is a sort of broth of decayed vegetation, often containing only one-fifth part of solid material, the rest being water, the whole forming a lake of soft mud varying in depth, which at Rotterdam is on an average 13 m. But the soil in question had been "improved" by sinking sand. It is possible to speak of an artificial sand-bank or bar in this case, because the site of the Wilhelmina Quay, at the top of which the landing-stage of the Holland-American line is situated, was a part of the River Maas, close to the left bank. In order to protect that top from the rush of the tide, which penetrates the Maas Estuary even beyond Rotterdam, a twig mattress (*zinkstuk*) had been sunk there.

Mr. Hennebique, when making the plans for this building, thought of substituting armed concrete pile for the wooden pile generally used in Holland in deep foundations. The sand-bank extended to within 12 m. of the top of the street. It was decided to use piles 20 m. long so that they would be embedded in the diluvial sand for a length of 8 m. Owing to various circumstances the enterprise, if not a total failure, was certainly a doubtful success. The piles, the cross-sections of which had the form of a three-cornered hat, were rammed in to a depth of 12 m. by a Lacour steam ramming machine. So far all went quite well, but the rest, when built up 8 m. higher, had to be driven in by dropping a block of iron weighing 2 500 kg., which often ended by shivering the concrete so that the pile had to be rebuilt. Moreover, those piles that had to be driven through the above-mentioned mattress or close netting of tough twigs went astray, the upper portion was built up in a vertical position and this crooked fabric would not budge for an avalanche of cast iron. Apart from the question whether this violence was not altogether uncalled for in a soil consolidated so long before, it will be understood that outsiders, at the sight of the ever-increasing heap of ruined concrete piles, iron rings and blocks, and effort after effort of monotonous futility, thought concrete piles and waste of money and energy synonymous. It will also be understood that, if the result had been otherwise, the imitation of the example would have benefited building enterprises of all kinds in Holland immensely. Even if the cost of materials were the same for the old and the new methods, it stands to reason that the waste of masonry, now rendered peremptory by the necessity of keeping wooden foundations below the ground-water level, would be avoided henceforth, and considerable expense saved.

In special cases of smaller importance, for instance, in a couple of buildings at Breda, pile work of armed concrete had been applied for high-level foundations through a mud-bank, but the length of the piles did not exceed 4 m. and they were easily let down into the solid sand.

There is a growing tendency, however, to substitute armed concrete for that special feature of native wood foundations which is not its best, *viz.*, the wooden floor and its caps, which are fixed to the piles by mortises and tenons. It is the fault of this tenon that

the efficacy of the pile is reduced 25 per cent. By using armed concrete the pile is entirely utilised. Fig. 7 shows the tops of the piles embedded in concrete about 1 ft. deep. Instead of a deal floor, a slab of armed concrete supports the masonry. The concrete between the piles is armed at the edges, and, some bars being carried up into the concrete overhead, the whole construction arrives at a

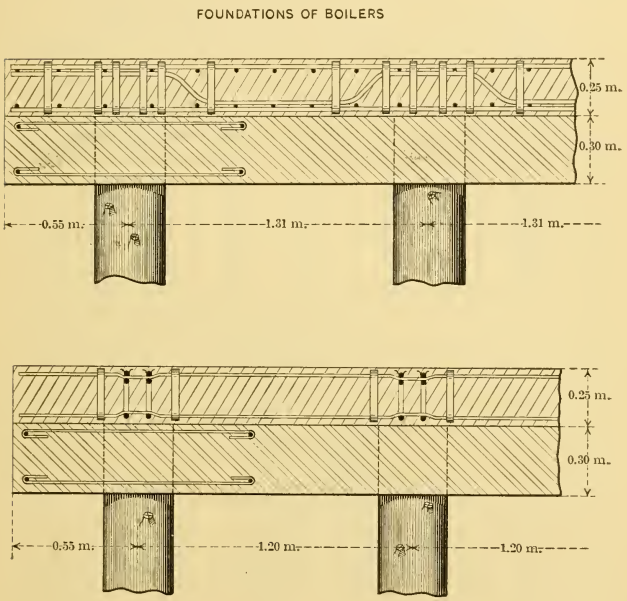


Fig. 7.

state of rigidity and inflexibility for which the material is generally famous. In the case here fragmentarily illustrated, the foundation is a slab 11.60 m. wide, 27 m. long and 0.25 m. high, propped up by 207 wooden piles, which are about 1.32 m. apart, center to center, a distance not allowed when wooden piles are used. This slab carries five hugh boilers, weighing, with their masonry, more than 3 000 000

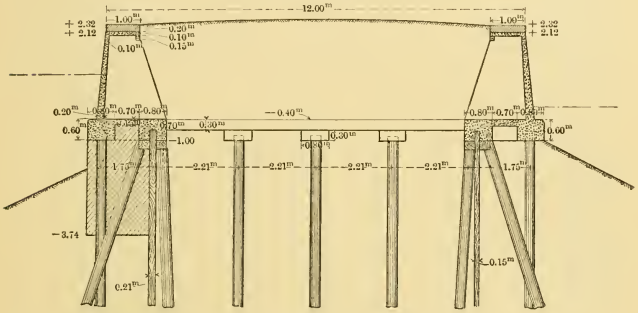
kg. The two 1 000-h.p. engines and dynamos, forming, with these boilers, the power plant of the South Holland Electric Railway Company, in its power station at Leidschendam, between Rotterdam and The Hague, weighing, with their foundation blocks of concrete, about 1 500 000 kg., are supported in the same way. The soil there being nearly as bad as at Rotterdam, the foundation of the engines would have proved a matter of great difficulty and expense, but for this material, which absolutely excludes all danger of vibration.

The same company that contracted for these foundations, the Dutch Armed Concrete Company, at The Hague, is at this moment engaged in building a huge cellar for the Government, at Ymuiden, under the supervision of the Royal Civil Engineers. It is 130 m. long and 24 m. wide, and is intended as a storehouse for fish to be sold at auction in the hall overhead. One of its larger sides is the existing quay wall. To the massive floor, a block of armed concrete, covering the whole surface, and 1 m. thick, are hung, so to say, a great number of conical blocks of concrete, not meant to support the floor, but to keep it down; for the tide runs up to about 1½ m. above the top of the cellar floor, hence the enormous weight of the floor itself. The conical blocks are placed bases downward. They have a coating of armed concrete about 2 in. thick, and are sunk by digging out the sand, while the soil around is drained by making wells and pumping them out. When the inverted funnel, about 3 m. high and 4 m. in diameter at the base, has disappeared below the surface, it is filled with concrete. Three cellar walls are of armed concrete, so is the ceiling, which is to be the floor of the auction hall.

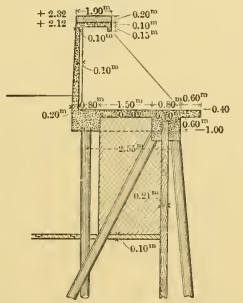
On the opposite side of the harbour a mighty quay wall, or rather a landing-stage, is being built, likewise of armed concrete, executed, as far as the fabrication of the material is concerned, by the Amsterdam firm previously mentioned. This landing-stage is supported by huge hollow cylinders, about 8 m. high and 2.5 m. in diameter. A powerful floating crane first carries into position a cylinder of sheet-iron of somewhat larger diameter and height. The sand is pumped out, the sheet-iron sinks lower and lower, and the crane lifts the armed concrete cylinder into the cavity thus made, after which the sheet-iron cylinder is withdrawn, and the armed-concrete cylinder filled with sand again. The same process

is repeated a few meters further out. Of course, the system of beams and cross-beams, floors, etc., together forming this landing-platform, is afterward built on this kind of pile-work. It needs no comment to show that this method of building quay walls has the

LOCK IN THE MERWEDE CANAL.



CROSS-SECTION OF DAM BETWEEN HIGH-LEVEL AND LOW-LEVEL CANAL.



CROSS-SECTION OF LOCK-CHAMBER WALL.

FIG. 8.

very great advantage of enabling the engineer to construct his work by easy stages, so as to give little trouble to traffic in so crowded a harbour as that of Ymuiden. But the plant required renders the use of these fantastic cylinders enormously expensive, and there is

no reason why concrete piles should not have been used, which would have allowed quite the same facilities, in addition to the extra one of driving in by water jet, for a mere nothing.

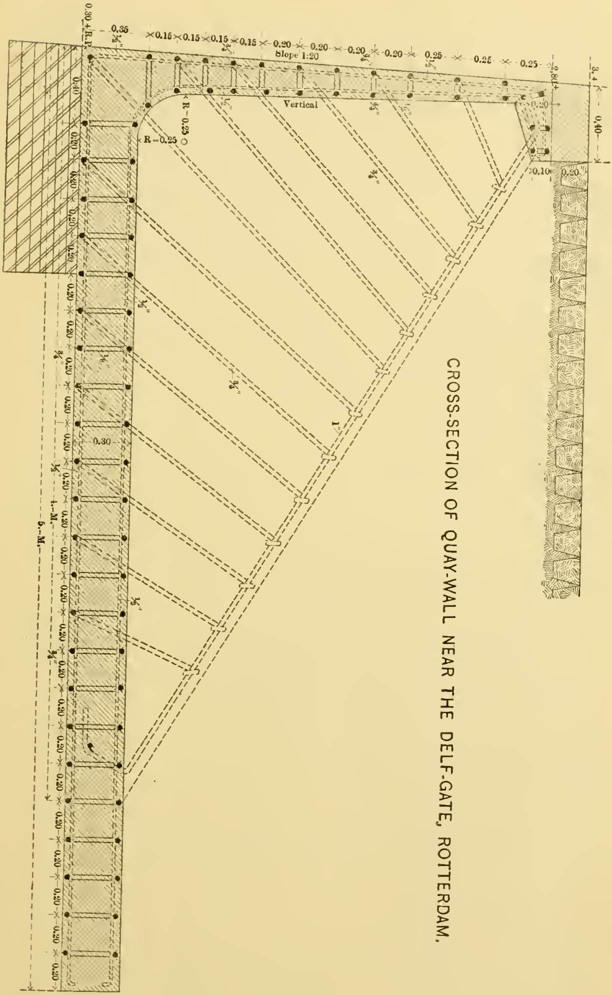
Another important work is being executed for the Government by the Dutch Armed Concrete Company of The Hague. In the neighbourhood of Utrecht a lock is building, parallel to an existing lock, beyond which the high-level canal is continued. This requires a very limited span, and the construction of a wall strong enough to resist the lateral pressure of the canal water. The cross-section of this is shown in Fig. 8, and will not need further explanation. The total length of the wall is 600 m.

After mentioning only two of the many tanks built: the septic tank built by the Government at Tilburg, executed by the firm of Stulemeyer & Co., of Breda; the gas-holder tank, 16 m. in diameter and 9.5 m. deep, by the same firm at Tiel; the series of applications to hydraulic engineering may be fitly closed by an account of the bridges of armed concrete built in Holland. They are not very important, compared with those built in France and Italy.

The first bridge, called Schollenbrug, was on the outskirts of Amsterdam. It was a vaulted bridge, having a span of about 5 or 6 m., and was armed by means of crossed bars.*

The energetic Director of Public Works of Rotterdam, Mr. G. T. de Joagh, gave a broad and open welcome to this new method of construction. He did not treat the new comer in the respectable old-world fashion, by holding him at arm's length and keeping an eye of distrust on him, while allowing him to do some work; but he took him into his office and into his building-yard, and let him have his way, to show what he could do; and, if he wanted him to build a bridge, he gave him the wherewithal to make a span of natural size and test it with double and treble the weight it had to bear. The result was a series of bridges planned and executed by the municipal engineer, Mr. S. J. Rutgers, having a span of 5.50, 6.50 and more meters. That across the Mallegat will have a span of 23 m., and is intended for ordinary and railway traffic. A large plot of ground, partly covered with spacious sheds, serves as a building-yard for the component parts of these bridges, and for a variety

*It is impossible to state correct particulars of the armed concrete works executed by the Amsterdam Monier Company, which was the contractor for this bridge also, because the firm refused to give them.



CROSS-SECTION OF QUAY-WALL NEAR THE DELF-GATE, ROTTERDAM.

Fig. 9.

of objects used for sewerage and street paving, among the former being oval-shaped conduits more than 2 m. high. This yard is, moreover, well supplied with testing plants, among which is an apparatus for testing beams, consisting of two I-iron girders, bolted together with strips so as to form a case. The beam to be tested is a short one, the extremities of which are solidly inserted in these cases, so that, without waste of material, it can be made to span any distance which the long iron girders will permit.

It would take too long to describe the construction of these bridges, which vary in character from the ordinary girder to the cantilever system.

A similar work, soon to be undertaken, is an underground canal, to take the place of an open one, done away with on account of the street traffic. It is 110 m. long, 5.5 m. wide and 5 m. high, and will be continued across the foundations of the railway viaduct, through Rotterdam, over a distance of 10 m., in which it is consequently to have no foundations at all.

It is evident from this short enumeration that armed concrete will, in a variety of cases, enter into competition with other materials in the construction of new works at Rotterdam. Indeed, no less than 5 400 cu. m. of armed concrete have been made in the past four years by the Board of Works of the City of Rotterdam. But the main sphere of action of such institutions is to keep existing works in a good state of repair, or to improve them. Quay walls are a source of trouble, especially at Rotterdam, with its miles and miles of basin and canal, and its muddy soil. So, when a stretch of wall near the well-known Delf Gate threatened ruin, it was simply broken down to the water-line, and a sheet of armed concrete was substituted, protected against toppling over by a floor-slab at the bottom, firmly connected with the wall by means of buttresses, as shown in Fig. 9. The body of sand resting upon this floor counterpoises the pressure of the upper strata against the wall, and, by taking away all lateral pressure, makes that on the wooden pile work, which also threatened to give way, a purely vertical one.

Another instance in which this material proved of exceptional utility is the following: At the end of a public garden a powerful pumping machine serves to drain the polder in which the lower

part of the city is situated, and, at the same time, to pump up the contents of a large sewage collecting tank into the adjoining river periodically. The dyke or fresh-water canal running through the delightful public garden formerly discharged itself into the tank, and the result of the "meeting of the waters" was odoriferous in the extreme. The only way to prevent this meeting was to lead the canal water directly to the pumps. The tank, made of masonry at great expense, the vaulted roof resting on several rows of brick pillars, would not allow of reconstruction. The use of a wooden or iron gutter was, of course, to be avoided. No sooner, however, did armed concrete appear on the scene than the problem was solved, at insignificant cost, and without the removal of one brick. A capacious canal, 1½ m. square, the sides being about 4 in. thick, supported by pillars of armed concrete resting on the tank floor, may now be seen winding through the cloistered subterraneous hall, avoiding the brick pillars. The inky fluid collected in the tank sometimes rises half way up the sides of the canal. Although no special precautions were taken, the concrete proved perfectly impermeable. The canal is always filled with clear water, and, though, as a rule, it is not even partially submerged, not a drop leaks through.

An ingenious construction of a somewhat similar nature was adopted by the Royal Military Engineers for the new military waterworks at Sloten near Amsterdam. The water is very ferruginous, and, before passing through the coke filters, passes a series of air-chambers through which it rains into the coke. A canal with a perforated bottom being needed, the Dutch Armed Concrete Company suggested a plan to make large holes in the bottom of a concrete canal and to place in these holes easily removable tinned sheet-iron boxes, perforated on all sides like salad-pails. The distribution of the water over the air-chamber and the coke-bed can now be regulated at will, and the iron baskets cleaned after taking them out.

Of late, acres of concrete floors have rendered numbers of buildings fire-proof, and have done away with many a nuisance, such as the hollow spaces between floors and ceilings, those trysting-places of vermin, microbes, dust and infected air. Several large warehouses and emporiums at Rotterdam, in one of which there are

pillars sustaining a load of 600 000 kg., a huge tobacco warehouse at Amsterdam, a rice mill at Zaandam, all of them five or six-story buildings, a new barracks at Gorkum, a hospital at Breda and an asylum for old women in that city, four governmental schools for young reprobates, a high school at Nymegen, the power station of the South Holland Electric Railway Company, and many villas and dwelling-houses have floors, often supported by columns, of armed concrete.

The power station, near The Hague, is also a kind of museum of curiosities on the subject. There are the foundations, already described, the floors and columns, a water-tank holding 12 cu. m.,

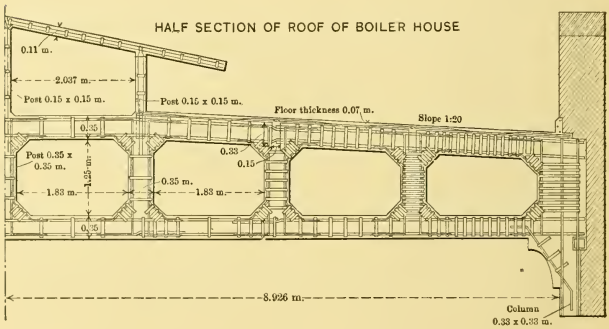
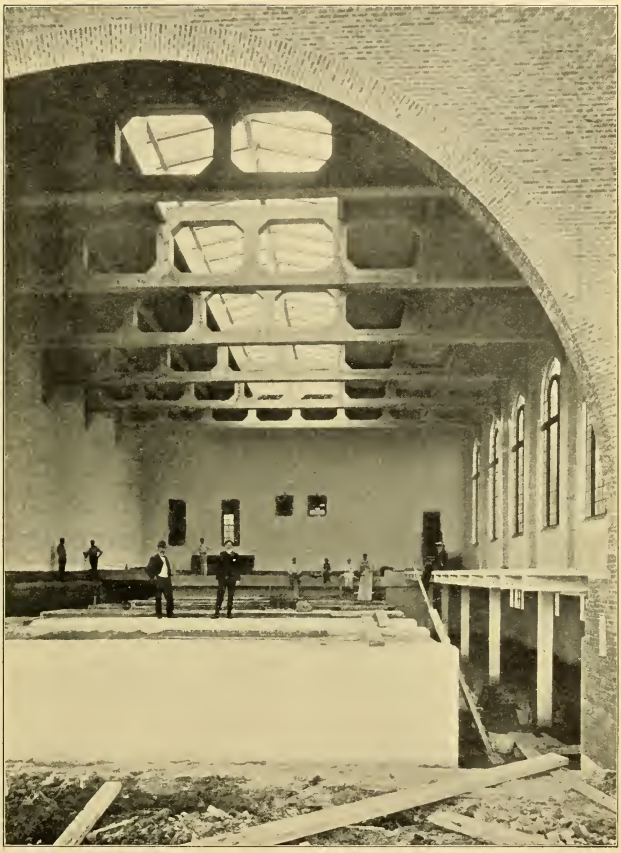


FIG. 10.

a huge chimney tunnel and economiser tunnels. There is an entire roof over the boiler-house, having open girders after the Vierendeel system (Fig. 10), and in the roof a skylight, 5 m. wide and 20 m. long, the glass panes of which are supported by armed concrete roofing moulds and sills (Fig. 11). The interior of the boiler-house is shown in Plate XV. There is the greatest curiosity; a chimney, 64 m. high (more than 210 ft.), made without scaffolding and without wood-casing. The chimney wall is only $\frac{1}{2}$ m. thick at the base and about half as thick at the top. It is lined inside and outside with a coating of armed concrete slabs, 4 cm. thick. The pipe itself is a cylinder, 2.5 m. in diameter, while the



INTERIOR OF BOILER-HOUSE, POWER STATION, NEAR THE HAGUE.

outer circumference is octagonal. The slabs were put together by means of grooves, so as to form an inner ring and an outer octagon, while iron bars pass up in the space between. The rings, ½ m. high, were firmly attached to the bars by wire, and the space between filled with concrete. There were two scaffoldings inside the pipe, which were alternately raised when 2 m., or four rings, had been finished. The basement is closely connected with the foundation slab by eight strong buttresses standing out from it about 2 m.; this slab is of the same nature as the one made for boilers and engines. It is supported by 88 piles. At a short distance from the power house is the carriage shed, 80 m. long, 30 m. wide, and entirely covered with a roof of armed concrete, supported by rafters, having a span of 15 m., and pierced by a skylight 10 m. wide and 70 m. long. The pits in the bottom of the shed, altogether about 350 m. long, and the floor, are likewise built of armed concrete.

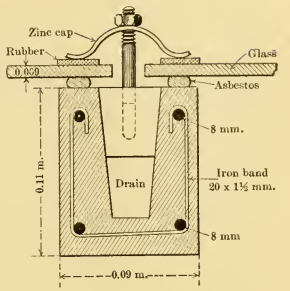


FIG. 11.

By far the most important and interesting work now in progress is the railway viaduct for the South Holland Electric Railway Company through the northern part of Rotterdam. A similar structure, indeed, arose in that city in 1900: a footbridge across a road 25 m. wide, which separated an extension of the municipal gas-works from the original factory. Two years later the State Railways had an overhead passage built across their line near Nymegen.

But a monolith of armed concrete a great deal more than a mile long (about 1 900 m.) is a spectacle the world has not yet beheld.

The reason why this material was chosen is the paramount one of economy—economy of space, of price, and cost of maintenance. There is another viaduct through Rotterdam, and it was a matter of great importance that a junction might be obtained at a given moment, which circumstance prohibited any difference of level between the two roads. On the other hand, the Rotterdam

Board of Works rightly prescribed a free passage, 5 m. high, underneath the viaduct. Consequently, the building space was, after deducting rail and sleeper, about ½ m. So, if the double-track viaduct had been made of constructed steel, the street bridges would have required piers, at least 8.50 m. broad, and the loss of building plot in this crowded part of Rotterdam would have amounted to about 4 000 sq. m., which means at least 100 000 guilders ($40 000). An elaborate plan and estimate of constructed steel was made, and proved, although steel prices were very reasonable, to surpass the cost of concrete by more than 30 per cent. There is, moreover, the opportunity to fit up the spaces underneath the arches as shops or offices, and thus to pocket a fair rent, which is out of the question when noisy steel construction is used.

The plan was made by the Dutch Armed Concrete Company of The Hague, whose chief manager, Mr. A. van Hemert, a civil engineer of scientific reputation in Holland, had previously, by the aid of elaborate and important experiments, of which he published an account, studied the elastic properties of the material. The width of the viaduct at the base is now only 5.50 m., as will be seen from the cross-section (Fig. 12). The part of the viaduct now being made is nearly 700 m. long, and crosses six streets, three of which are 20 m. wide, and one 30 m., but the latter is crossed by two spans 13.50 m. each. The most remarkable span is the one across the Zomerhofstreet. It is oblique, and its length, therefore, increases to 21.70 m. To complicate matters further there is a curve in the road at this place, having a radius of 200 m. For all that the four arched main girders, each under a rail, measure no more than 0.40 by 0.45 m. at the top, though no less than 0.40 by 2.30 m. at the springing line, and have to sustain the weight of two large type locomotive engines weighing 104 000 kg.

The piers, on the contrary, are extremely bulky. They consist of an armed concrete casing filled with weak concrete, and weigh, as far as the larger spans are concerned, about 300 000 kg. each. The foundations of the viaduct had been laid before armed concrete was decided upon, but the weight of the superstructure was a matter of secondary consideration, because the greater part of the 6 000 piles that were rammed in, serve merely for the consolidation of the mass, in a soil so muddy that a length of pile of 22 m. proved

necessary here and there. It is needless to say that the cost of these foundations nearly equals that of the superstructure.

The original plan for using constructional work for the iron skeleton has been carried out as far as the rectangular part of the viaduct is concerned. It was abandoned for the curves, where bars and strips are used. Besides the advantage of fixing the iron immovably in the exact position it is intended to occupy, constructional work proved cheaper in labour and time.

As will be seen from the cross-section, the track is laid in a

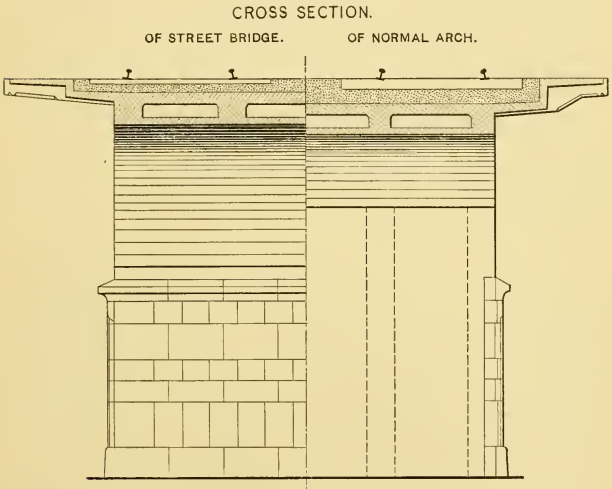


Fig. 12.

gravel bed, which, over the normal arches, is deep enough to allow wooden sleepers to be used; over the street bridges, however, steel ones were preferred. The whole of the surface, including that of the overhanging platform on each side of the railroad, is asphalted, so as to be perfectly water-proof, and the gravel bed is properly drained by sewer-pipes, for which purpose moreover the floor is made slightly slanting from the middle outward; the platforms, on the contrary, are sloping inward, forming two shallow gutters. All the columns and piers have stone facings, 3 m. high, alongside the

public street. The rest of the superficies is coated over with a plaster of pulverized stone and cement, which, though well known to the visitors of the Düsseldorf Exhibition of 1902, is used for the first time in Holland. This coating is butted in together with the concrete, and, although it is only 3 cm. thick, and here and there more than 2 m. high, its fabrication has not given rise to serious difficulties. The stone-mason and even the sulptor have been called upon to give a tasteful finish to the whole.

The æsthetic value of armed concrete is a very open question from the standpoint of a modern architect. It is also an open question whether those architects who decreed that value *nil*, at the International Congress of Architects of 1904 at Madrid, had any notions of the progress of engineering since the Middle Ages. It is a direful truth that to the influence of architects on the outward appearance of the masterpieces of modern engineering may be applied the word of Siéyès on the Third Estate of France at the beginning of the French Revolution: "What should it be? Everything. What is it? Nihil."

If it appears from this account that the arms of King Concrete score victories in Holland, it may not be inferred that His Majesty lacks his due Opposition, whose leader, Mr. Hackstrol, a Captain of the Royal Military Engineers, performs his duty with much sense and spirit. He avers, and undeniably proves, that the theory of Mr. Considère, who increases tenfold the resisting faculty against tension of concrete, when armed, is false; consequently, that, if the tension of the iron bars is allowed to surpass 200 or 300 kg. per sq. cm., fissures will appear in the concrete, which are sure to bring down the construction in the long run, when the iron has decayed by rust. That, on the other hand, when less than 300 kg. of tensional resistance per sq. cm. is utilised from the iron skeleton, its presence is not to be defended from an economical point of view, and unarmed concrete might do as well. It is hardly necessary to observe that these arguments, however sensible and salutary in their effect to warn against overtaxing the iron skeleton, are at fearful odds against such as economy of space, of cost of maintenance, absolute safety against fire, solidarity of component parts of constructions, excluding lateral deviations, endowing them with an individuality, which it had hitherto not been given to humanity to bestow on the work of its hands.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 74.

CONCRETE AND CONCRETE-STEEL.

CONCRETE-STEEL BRIDGES.

By Dr. Fritz von Emperger, C. E.

In a paper, entitled "The Development and Recent Improvement of Concrete-Iron Highway Bridges," presented before the American Society of Civil Engineers in 1894, the writer tried to review the development of concrete-steel up to 1894, and to bring the constructive and economical advantages of this combination to a broader knowledge in the Profession.* The discussion called forth by that paper gives a good deal of information concerning the difficulties encountered at that time. It is a matter of great satisfaction to notice how much things have changed during the short interval of ten years. The difference between now and then is so remarkable that the writer feels obliged to go over the same ground as that covered by his paper of 1894, as far as the limits of these publications will allow.

Ten years ago the number of concrete-steel bridges was so small that there would have been no difficulty in giving a complete list, whereas now it would be quite impossible to give such a list, conse-

* *Transactions*, Am. Soc. C. E., Vol. XXXI, p. 438.

quently one must be content to mention the most important structures.*

With the astonishing increase in the number of concrete-steel bridges, there may be noted, also, the appearance of a variety of systems, each being more or less an improvement on the primary construction, although, as a matter of course, a great many so-called systems cannot rightfully make claim to any improvement or originality over older systems.

In 1894 the writer could only mention three systems of concrete-steel bridges.

1.—The so-called Monier construction, which provides for two sets of wire netting, one near each side of the arch;

2.—The Wunsch system, characterized by two series of armatures of rolled sections, one horizontal, and the other curved;

3.—The Melan system, showing curved I-beams or arched latticed girders.

It is seen from this list that, at that time, it was considered that only arched bridges should be constructed of concrete-steel.

I.—Concrete-Steel Arch Bridges.

One of the first changes made, following the introduction of these three systems, was that suggested by E. Thacher, M. Am. Soc. C. E., who proposed using flat steel bars, independent of each other, near the intrados and extrados of the arch. These bars are subjected to tension or compression only. That part of the steel, which in the Melan system is represented by the web of the arched ribs, is saved, but the concrete must take all the shearing stresses without aid from the steel.

* No better account of the amount of work done since can be made than by giving the number of bridges built by Hennebique:

1894.....	5 bridges.	
1895.....	3 "	
1896.....	10 "	longest span of girder of Yverdun, 42 ft. (13 m.)
1897.....	13 "	longest span of girder of Lausanne, 49 ft. (75 m.)
1898.....	29 "	among them the floor of Molineaux R. R., Paris, with a 52.5-ft. (16-m.) span.
1899.....	42 "	among them, Bridge of Chatellerault, 2 arches of 131-ft. (40-m.), and 1 arch of 167-ft. (50-m.) span.
1900.....	56 "	
1901.....	71 "	
1902.....	101 "	
1903.....	109 "	longest span of girder, 66 ft.

To which number, of course, not only a great number of other firms, but also all the former agents of Hennebique, who work at present independently, had to be added.

FIG. 1.—MELAN ARCH BRIDGE, LAIBACH, AUSTRIA.

FIG. 2.—FOOTBRIDGE OVER LUSTHOFSTRAAT, ROTTERDAM.

This idea led to a combination of both systems, which consists in placing a number of flat steel bars between the arched girders. A similar construction was used by Mr. Morsch, at that time Chief Engineer for Wayss and Freitag, at present Professor at Zurich, for his bridge over the Mosel Railway at Wasserliech,* where a number of round steel bars are placed between the built-up girders. It is known that the advantage of the Melan system is to hold the concrete firmly between the flanges of the steel ribs. Therefore, if bars are placed between the steel ribs, as mentioned before, by connecting them transversely, the result is a co-operation of materials similar in result to that attained by Considère's hooped concrete.

Another variety introduced in recent years in the building of concrete-steel arches is the application of three hinges, two at the springing lines and one at the crown. The first bridge of this kind was a Melan bridge, built at Steyer, Austria, in 1898. It has a span of 137.8 ft., and a rise of only 8 ft. 8 in. A bridge of the same type, built in 1900 at Laibach, Austria, is shown in Fig. 1, Plate XVI, and in Plate XVII. It has a span of 108.3 ft., and 13 ft. 4 in. rise. The bridge encloses fourteen steel arches, each consisting of four angle irons, $3\frac{1}{2}$ by $3\frac{1}{2}$ by $\frac{1}{2}$ in., latticed together. The steel arches are connected transversely at four points. The concrete (1:3:6) has a thickness of 19.7 in. at the crown, 27.6 in. in the middle of each segment, and 25.6 in. at the haunches. The facade is built of concrete (1:4). The arch is 50 ft. wide, over all, and carries a roadway, 32.8 ft. wide, and two sidewalks of 9.8 ft. The hinges consist of step-bearings for each steel rib and special artificial stone blocks set into the concrete with a lead plate, $\frac{1}{16}$ in. thick and 4 in. wide. The steel section in the arch ranges from 1.24 to 1.73% of the concrete section at different points. The total weight of steel in the bridge is 102 896 lb. or 20 lb. per sq. ft. of the horizontal arch projection. The total cost of the bridge was about $32 000, including the railings.

In some bridges designed on the Melan principle by the writer, when in the United States, he has placed the ribs, not parallel to each other, but diverging from crown to springing lines, making the arch wider at the springing lines than at the crown in order to

* *Beton und Eisen*, No. 2, 1903, p. 71.

attain a firmer connection with the abutments and using only one joint at the center.

A similar construction was applied by Professor Melan in his bridge at Payerbach, Austria.* This method of construction, in which the arch is most intimately connected with the skewback, divides the arch into two corbels which support each other by their horizontal thrust.

The idea of strengthening the arch by using the spandrel walls, as already shown in the Wunsch system, was taken up by Mr. Hennebique. He was the first to build plates of larger span with a vaulted underside. He reinforced these plates with arched ribs. The first application of this principle in a bridge of any considerable span as far as the writer is aware, was in a bridge of 45 ft. span, built for the World's Fair in Paris in 1900, near the Quai Debilly.† In that bridge there is a plate of 8 in. thickness, reinforced by ribs from 8 to 9 ft. apart, each rib being armored with 1¼ in. round bars, three near the top, and seven near the bottom. The ribs were 12 in. high in the middle, and 35 in. high at the abutments. The building of the structure was not permitted until a test span of the same dimensions had been built and tested. The principle underlying this idea can be compared with the strut frames in wood construction, where, by a similar arrangement, the span can be increased considerably with the aid of brackets and corbel-pieces.

The importance of a construction of this kind is to be found in the fact that it permits the reduction of the dead load of a bridge to the utmost, and, since in bridges of larger span, the dead load is almost the only one which comes into consideration, this construction seems to be well suited for them.

The first highway bridge of this kind constructed by Hennebique was the bridge over the River Vienna at Chatelleraut.‡ It has three spans, a middle span of 164 ft. and two side spans of 131 ft. each. The rise of the arches is one-tenth of the spans, and the bridge is 26 ft. wide, over all. The whole structure is one piece, without joints, and consequently shows a number of cracks.

An interesting example of a bridge of this kind of construction

* *Beton und Eisen*, No. 5, 1902, p. 30.
† *Le Beton Armé*, April, 1900.
‡ *Le Beton Armé*, November, 1900.

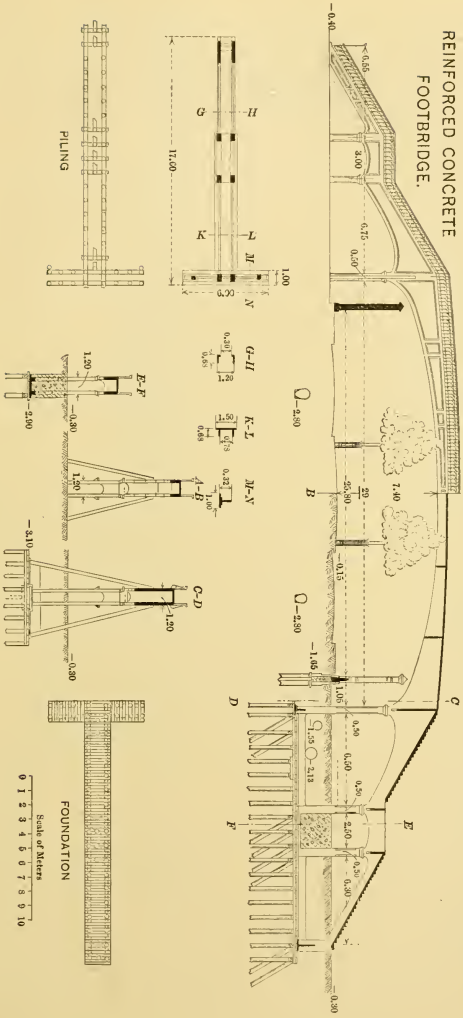

REINFORCED CONCRETE
FOOTBRIDGE.
PILING
FOUNDATION
Scale of Meters
0 1 2 3 4 5 6 7 8 9 10
G-H
K-L
M-N
A-B
C-D
E-F
A
B
C
D
E
F
G
H
K
L
M
N
17.00
6.00
1.00
3.00
0.75
0.50
0.15
0.30
2.50
2.13
2.80
1.05
1.65
7.40
1.20
0.80
2.00
3.10

FIG. 13.

is the footbridge over the Lusthofstraat, in Rotterdam, Fig. 13, and Fig. 2, Plate XVI. This bridge consists of a main span of 95 ft. and two side-spans of 19¾ ft., the pillars between the spans being only 19.7 in. wide. The main span consists of a 4-in. plate, 4 ft. wide, reinforced by two ribs 2 ft. high in the center, and about 10 ft. high at the pillars.

The construction of this work was commenced on September 2d, 1901, and was entirely completed on October 29th of the same year. The centers were struck on November 23d, and during the same winter a loading test was made in the presence of M. Considère. It is of some interest to note that this bold structure has withstood the severities of the climate very well, and that investigation made by a friend of the writer for the purpose of this paper showed only two cracks on the upper side, symmetrically situated in the middle of the two smaller spans, a phenomenon which justifies the supposition that these two smaller arches must counterbalance the corbel action of the larger one, and that the two cracks in the side arches prevented the opening of a crack in the center arch.

This example contributes a further proof of the usefulness of hinges, although they are not an absolute necessity. If the structure is allowed to develop cracks, these will act as hinges. The possibility of the opening of such cracks may be reduced by careful construction, but the writer thinks that one of the most important advantages gained in the use of hinges is the greater independence of the structure from the execution of the work. In addition, there are the statical advantages, which simplify the calculation and which result from the fact that the position of the pressure line is fixed. At any rate, irregular cracks cannot be considered as an advantage to the appearance of a bridge, especially as they are easily noticed in a concrete surface without a stonelike treatment or a stone cover.

This principle in arch construction, of using ribs carrying a floor, was developed further by Hennebique and others through the introduction of transverse connections between ribs and the plate which carries the street. By this means there is obtained an arch framework, consisting of upper horizontal chords, carrying the girders and joists for the street floor and the consoles for the sidewalks and the railings, lower arched chords and frame-like connections between those chords and between the ribs.

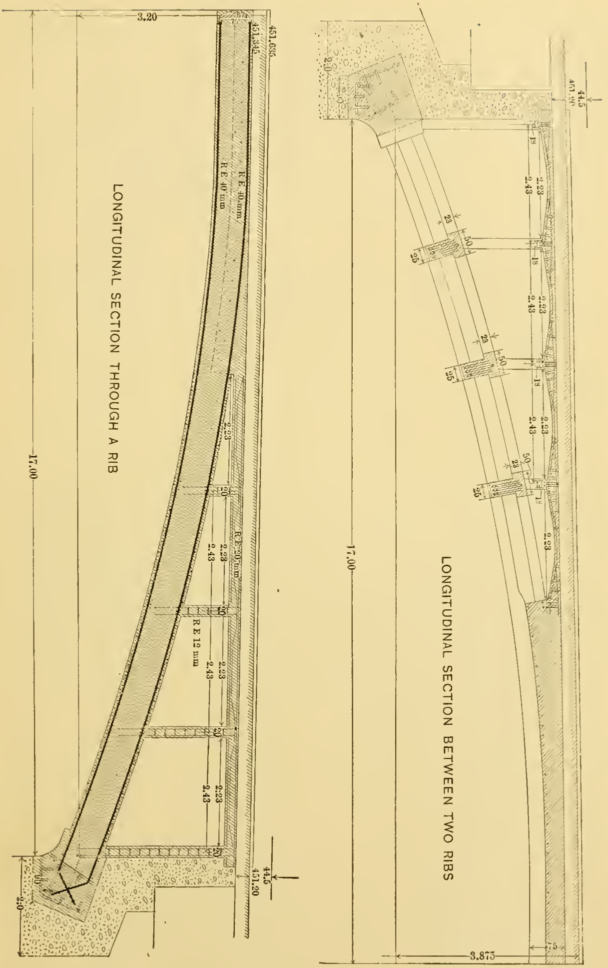

LONGITUDINAL SECTION THROUGH A RIB
LONGITUDINAL SECTION BETWEEN TWO RIBS
3.20
17.00
451.635
451.345
451.20
44.5
R.E. 40 mm
R.E. 20 mm
R.E. 12 mm
2.23
2.43
3.875

Fig. 14.

The execution of this idea has been promoted by the invention of hooped concrete by M. Considère. The section of compressed members, especially arched ribs, can be reduced to at least one-half by the use of this material, considering the fact that hooped concrete has more than twice the strength of ordinary concrete. Thus, instead of 600 lb. per sq. in. 1 200 lb. per sq. in. can be taken as allowable stress, and, needless to say, this circumstance will be decisive in many cases when such concrete-steel structures come in competition with steel bridges, and the question of economy is raised.

The writer recently designed for the City of Feldkirch, Austria, an arch bridge with a span of 112½ ft., contemplating the use of arched ribs of hooped concrete. Although this design has not been executed, it may be of interest to describe it briefly, in order to illustrate to what extent Considère's invention of hooped concrete may be used in concrete-steel bridges (Figs. 14, 15 and 16).

The calculation was based on an equally-distributed live load of 80 lb. per sq. ft. and a concentrated wheel load of 3 tons.

The design shows four ribs of octagon section, 29½ in. in diameter. The hoops, of $\frac{5}{16}$-in. wire, have a diameter of 26¾ in. Under these conditions, the calculation for the arch without hinges and for the most dangerous position of loading gave a maximum compression of 967 lb. per sq. in. and a maximum tension of 22.8 lb. per sq. in. The calculation was made without considering the material aid from the framework of the superstructure, because the value of such aid has not yet been fully ascertained by tests. The calculation for the arch with hinges gave no material difference from the above-named stresses.

The hinges were designed with the idea of adapting them to the special conditions of hooped concrete construction and not simply to imitate hinges used in steel bridges. In the majority of cases the hinges are enclosed with concrete after the completion of the work. They have done their work when the centers are struck and the concrete masonry has been allowed to set in the two halves of the arch, independently of each other. After the lengths of the arch segments have thus been fixed so that they can only be changed by temperature changes, the presence of hinges will only serve to prevent the development of cracks at undesirable points. Such cracks

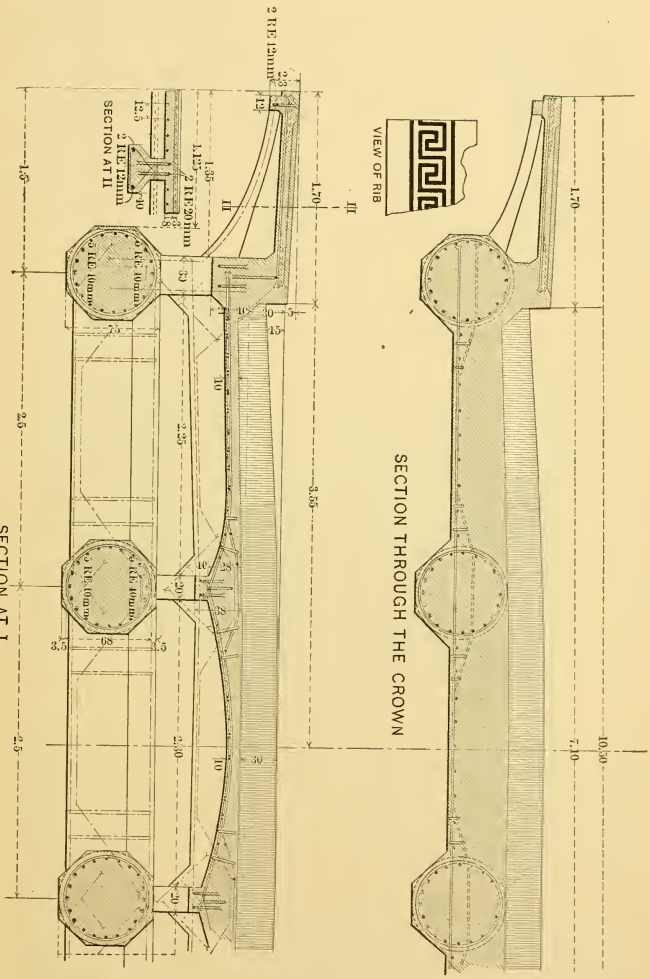

SECTION AT I
SECTION THROUGH THE CROWN
VIEW OF RIB
SECTION AT II
2 RE 12mm
2 RE 20mm
5 RE 10mm
1.70
3.55
10.50
7.10
2.5
1.5
1.35
1.125
2.25
2.30
3.5
68
75
10
15
20
28
30
38
39
40
5

FIG. 15.

must develop in the weakest section, and the arrangement at the haunches, therefore, is made stronger to a sufficient extent to prevent the appearance of cracks at that place, even if the abutment makes some slight movement, which is quite likely to occur, under the pressure from the arch. It is left to the center hinge to take up all primary movement, it being left open until after the centers are struck, but it is closed with concrete afterward in order to satisfy the statical conditions of the calculations. If the temperature stresses should afterward develop a crack in this arch at the center point, the difference of 48° fahr. would not add to the stresses

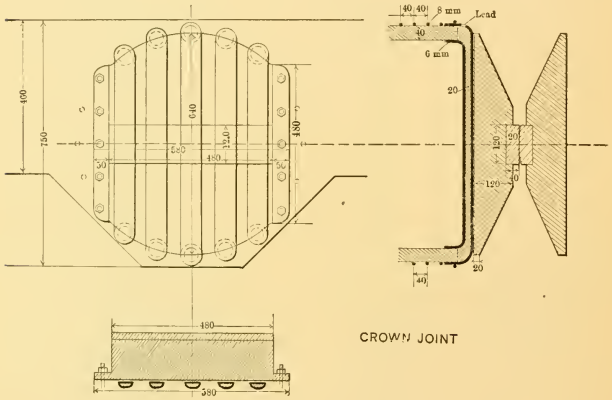


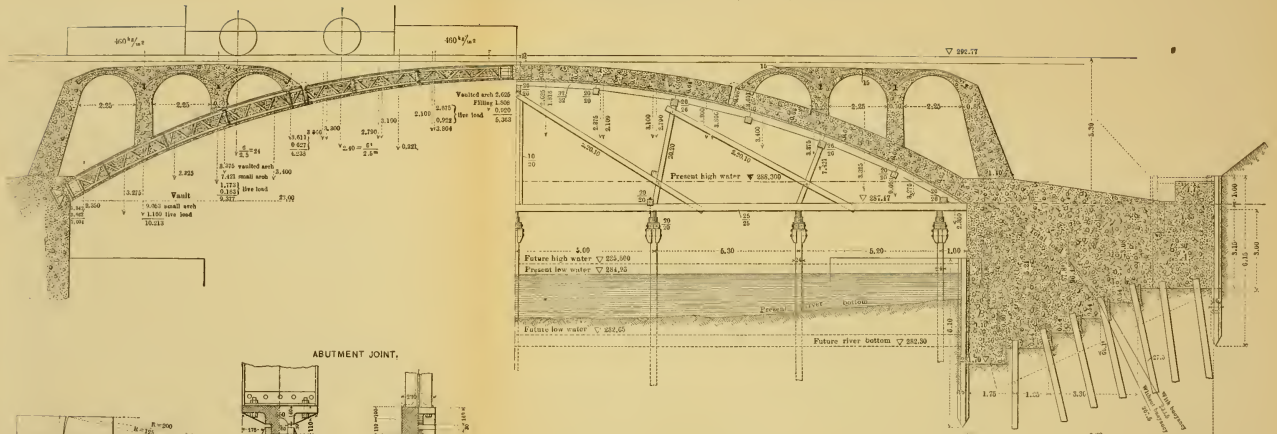
FIG. 16.

mentioned more than 8 lb. per sq. in. in tension, which would give a maximum tension of 30 lb. per sq. in., which is so small that it would be permissible in plain concrete. The writer believes that a center joint is an important detail which should be used in many cases for single arch spans.

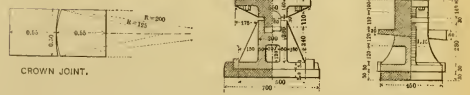
II.—CONCRETE-STEEL BEAM BRIDGES.

In the writer's paper, mentioned previously, no mention was made of girder bridges, although it must be acknowledged that the first

MELAN ARCH BRIDGE WITH THREE HINGES, AT LAIBACH, AUSTRIA.



ABUTMENT JOINT.



attempt to build such bridges had been made about ten years before, when Monier tried to construct large slabs of reinforced concrete. In 1887 G. A. Wayss had built floor slabs of 9 ft. span, and had also described clearly the correct place and purpose of the embedded steel, and M. Koenen had published the first method of computation for reinforced concrete beams. Up to 1894, however, these attempts were considered to be of a purely experimental character, and of such small commercial value that the writer did not then feel justified in placing them before the Profession. The year 1894, however, witnessed a notable change in the status of reinforced concrete beams. A considerable number of tests had then been made, in different parts of the world, and the general introduction of the new construction into practice resulted therefrom. In France and the adjoining countries it was mainly due to the work of Hennebique, Demollins, Coignet and Tedesco; in Holland the most prominent work was done by Sanders; while the German engineers seem to have rested at that time on their former laurels, and, only by way of completing the records, may be added the tests made by G. H. Wayss in Vienna in 1890, and several tests made by the writer in New York in 1894. One of the latter tests is described in a paper by George Hill, M. Am. Soc. C. E.*

Much was due to the introduction of the bent-up rod and the stirrup, in the evolution of the progressive career of reinforced concrete beams. The importance of these details, which tend to join safely all parts of the beam, is best shown by the fact that the general practice followed this form of construction with increasing confidence.

The Hennebique method of construction was limited to plain round bars of iron or steel, of small cross-section, and with sufficient surface to provide the required adhesion. The dependence on the adhesion alone of the steel to the concrete formed one of the difficulties of this system. This difficulty has been removed by the introduction of such bars as the Ransome, Thacher, etc., which secure the embedded steel against sliding by the geometrical form of the bars. The attempts to use rolled steel of larger sections, however, were not successful until a method had been developed which has recently been brought out. As shown in Fig. 17, it consists in a series

* "Tests of Fire-Proof Flooring Material." *Transactions*, Am. Soc. C. E., Vol. XXXIV p. 542.

of band-like stirrups which pass through holes punched in the rolled section and have a definite bearing against the web of the section.

It has been stated by Hennebique that the first girder bridge of reinforced concrete was built by him in 1893 as an approach to a mill at Don, Departement du Nord, France. The progress of this construction since then is given in the list of works built in accordance with his system.*

It is extremely difficult to treat of theory and deduce formulas in what purports to be a review, but, remembering some previous criticism, the writer will at least make an attempt to establish some simple methods of computation.

It is one of the peculiarities of reinforced concrete construction that the stresses in the materials under working loads cannot be computed exactly, but that the ultimate stresses caused by the breaking loads can be ascertained with sufficient accuracy from the properties of the two constituent materials. The following procedure is known to be one of the simplest methods of computation.† It is based on the conditions as they prevail under the breaking load (Fig. 18) from which the allowed load is deduced by a factor of safety.

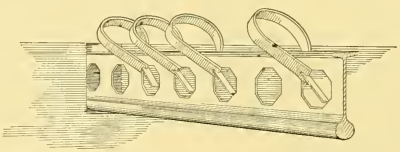


FIG. 17.

First, consider a reinforced concrete beam having a total depth, h, and a width, b. The total cross-sectional area of the concrete, $F_c = b\,h$, and that of the reinforcing steel is F_s. Per unit of width, therefore, the area of the steel is $f_s = \frac{F_s}{b}$.

Let d = the distance from the top of the beam to the center of tension;

d' = the distance to the neutral axis;

* *Beton und Eisen*, Nos. 3 and 4, 1904.

† *Beton und Eisen*. No. 3, 1904, p. 171.

$d - d' = y$ = the distance from the center of tension to the neutral axis;

m = the distance between the centers of tension and compression.

It will be assumed that the compressive and tensile stresses are uniformly distributed over their respective sections (Fig. 18).

The conditions of equilibrium require that the moments of the external forces be equal to the moment of the internal stresses.

$$M = P\,m = T\,m,$$

where P indicates the resultant of the compressive stresses and T that of the tensile stresses. If ζ_c denotes the compressive stress in the concrete per unit of area, and ζ_s the tensile stress in the steel per unit of area, then:

$$P\,m = b\,d'\,\zeta_c\,m = T\,m = F_s\,\zeta_s\,m.$$

The moment of resistance of the concrete will be

$$W_c = b\,d'\,m$$

and that of the steel

$$W_s = F_s\,m.$$

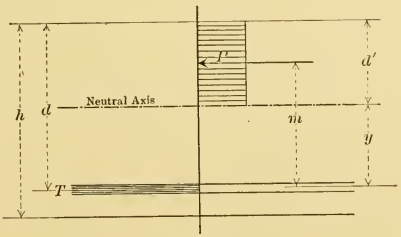


FIG. 18.

For the purposes of this calculation only the moment of resistance of the steel is of interest. It depends on the comparative amount of steel embedded. If the sectional area of the steel be expressed in that of the concrete, and the percentage of reinforcing metal be denoted by p,

$$F_s = b\,d\,p,$$

and its moment of resistance,

$$W_s = b\,d\,p\,m,$$

or, reduced per unit of width,

$$W_s = d\,p\,m.$$

The position of the neutral axis becomes fixed as soon as the percentage of reinforcing metal, p, is assumed; and if the ratio of the coefficient of elasticity of the steel to that of the concrete at the breaking point be taken as 15, a close approximation to the position of the neutral axis is given by

$$d' = -15\,d\,p + d\,\sqrt{15\,p\,(15\,p+2)},$$

and

$$m = d - \frac{d'}{2} = \frac{d}{2}\left[2 + 15\,p - \sqrt{15\,p\,(15\,p+2)}\right].$$

The moment of resistance of the steel may then be written:

$$W_s = \frac{b\,d^2}{6}\,3\,p\left[2 + 15\,p - \sqrt{15\,p\,(15\,p+2)}\right] = W\,C_s,$$

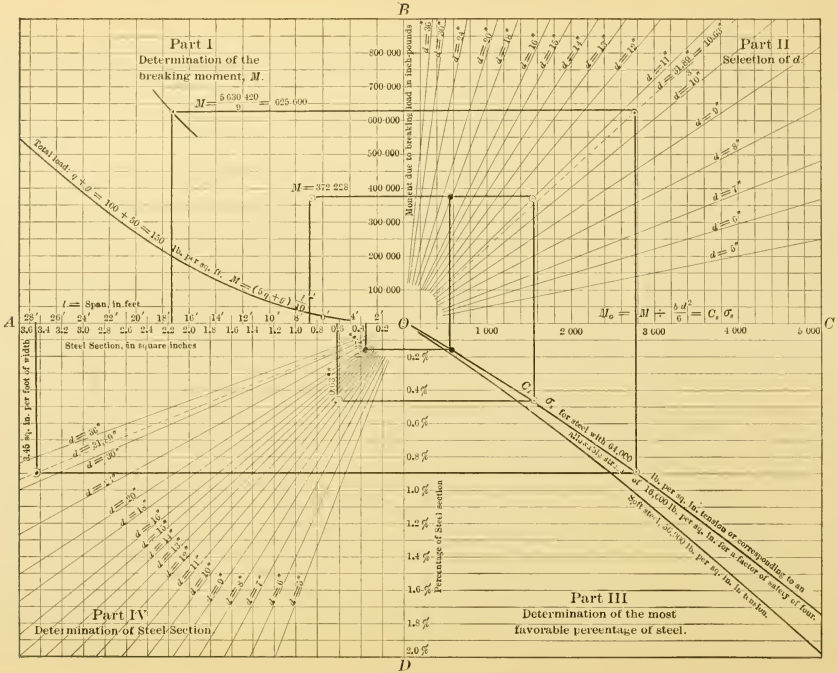
and the breaking moment

$$M = W\,C_s\,\zeta_s.$$

The last equation contains all the factors entering into the design of the beam, those given directly by the conditions of the case as well as those which are unknown and have to be determined by computation. M represents the breaking moment of the beam, and contains the effect of live and dead loads, of the span and the factor of safety; W stands for the moment of resistance of a concrete beam without reinforcing of the depth d, and the width b; C_s is, as can be seen from the foregoing, a constant dependent on the percentage of reinforcing metal only; ζ_s indicates the tensile strength of the steel used per unit of sectional area. The results of the final equation are plotted in Fig. 19, entitled, "The Graphical Computation of Reinforced Concrete Beams." This diagram is arranged so that the effects produced by any change in the assumed quantities are easily ascertained, and the desirability of making such change can thus be decided conveniently. The diagram is divided into four parts, a brief description of which is as follows:

Part I.—This part is devoted to the determination of the breaking moment, M. On the axis, $O\,A$, the spans, in feet, are taken as the abscissas; and, on the axis, $O\,B$, the breaking moments are plotted as ordinates. For instance, take the live load, $q = 100$ lb. per sq. ft., and the dead load, $g = 50$ lb. per sq. ft. In floor construction, the breaking load is usually taken as

$$M = \frac{5\,q + g\,l^2}{10};$$



GRAPHICAL COMPUTATION OF REINFORCED CONCRETE BEAMS

FIG. 19.

but, in other cases, especially for bridge construction, it is taken as

$$M = \frac{4\,(q+g)\,l^2}{8}.$$

In the latter case, there is no difficulty in using the diagram directly for an allowable load and its corresponding moment by simply changing the scale of the moments to one-fourth, and in Part III of the diagram, in using the allowable working stresses, which are one-fourth of the ultimate stresses, by the aid of the same change of scale.

Part II.—This part, in common with Part I, has the line, $O\,B$, and is intended to reduce the primary equation to the form

$$M_o = \frac{M}{W} = C_s\,\zeta_s.$$

Since $W = \frac{b\,d^2}{6}$, all that is necessary to obtain M_o is to divide M by $\frac{b\,d^2}{6}$, considering that, for the values of the diagram, $b = 1$, $W_o = \frac{d^2}{6}$. The values of M_o are thus obtained in Part II as a number of radiating lines marked correspondingly $d = 5''$, $d = 6''$, etc.

Attention should be called here to the fact that this part of the diagram can be used, whatever may be the values of the span, l, and the depth, d, without regard to the scale. If, for instance, the length of the span, l, exceeds the values in the diagram, the quantity, $\frac{l}{n}$ need only be introduced to obtain the value, $\frac{M}{n^2}$, which is equivalent to a reduction in scale of $\frac{1}{n^2}$. If then the line, $\frac{d}{n}$, is taken, the scale is again multiplied by n^2, and the same result is obtained on the axis, $O\,C$, as by disregarding the scale altogether.

Part III.—This part of the diagram, as explained previously, gives the values, $M_o = C_s\,\zeta_s$, on the axis, $O\,C$, and on the axis, $O\,D$, the most advantageous percentages of the metal, p. Plotting the computed results, a certain curve is obtained. Two such curves are drawn on the diagram. One is for a greatest tensile stress, $\zeta_s = 64\,000$ lb. per sq. in., according to the American practice, with medium steel, and the other for $\zeta_s = 4\,000$ kg. per sq. cm. (56 900 lb. per sq. in.), according to the European practice, with soft steel. Common practice limits the percentage, p, between 0.3 and 1.0%, and within these

limits it has been found that the allowable compressive stresses on the concrete need not be considered.

Part IV.—This part of the diagram has as its only object to furnish the quantities of steel required per unit of width, $f_s = p\,d$. They are given by a series of radiating lines marked with the corresponding values of d. The values of d, accepted from Part II, must also be used in Part IV.

To illustrate further the use of the diagram, Fig. 19, the following examples are given:

Example 1.—It is required to construct a railroad culvert of reinforced concrete of 5.9 ft. clear opening. The dead load on the structure is about 300 lb. per sq. ft. The greatest load on an axle of a European locomotive is 16 metric tons at present, but it is common practice to assume it to be 20 tons; the distribution of the load is determined by the distance from center to center of tracks, which is 13 ft. For a span of 7 ft. from center to center of bearings the greatest bending moment is 93 057 in-lb. per ft. of width, or 351 955 kg-cm. per m. of width. Knowing the moment, the depth of beam to be adopted and the quantity of steel required for it must be determined. In Fig. 19 two solutions are given for this case: One for the depth, $d = 11$ in., and one for $d = 18.1$ in. The Austrian State Railways, for which the design under consideration has been made, specify an allowable tensile stress in the metal of 758 kg. per sq. cm. = 10 780 lb. per sq. in., and a compressive stress in the concrete of 35 kg. per sq. cm. = 498 lb. per sq. in.

For the sake of illustration one of these computations is given: Let the depth of the beam $d = 11$ in. = 28 cm., and let it be reinforced with ten steel rods of 16 mm. diameter for each meter of width. The total area of the steel per meter of width will then be 20 sq. cm., or, per centimeter of width, $f_s = 0.2$ sq. cm. Substituting in the previously deduced expression for d':

$$d' = -15 f_s + \sqrt{15 f_s (15 f_s + 56)} = -3 + \sqrt{3\,(3 + 56)}$$
$$= 10.3 \text{ cm.}$$

The distance between the centers of tension and compression,

$$m = y + \frac{d'}{2} = 22.9.$$

$$W_s = F_s \times m = 458.$$

$$\zeta_s = \frac{351\,955}{458} = 768 \text{ kg. per sq. cm.}$$

Adhesive Stresses.—If k denotes the adhesive stress of the rods per centimeter of length, δ their diameter and S the greatest shear in the beam:

$$k = \frac{\delta}{4} \frac{S}{M} \zeta_s.^*$$

Substituting the numerical values in the last equation,

$$k = \frac{1.6 \times 6\,548}{4 \times 351\,955} \times 768 = 3.7 \text{ kg. per sq. cm.}$$

Longitudinal Shearing Stresses at Neutral Axis.—According to L. A. Sanders,† the greatest longitudinal shear can be safely computed as

$$1.5 \frac{S}{F_c} = 1.5 \frac{6\,548}{3\,000} = 3.27 \text{ kg. per sq. cm.}$$

Both of these results give stresses well within allowable limits.

Finally, the vertical shear due to a concentrated load may be considered. Let it be assumed that a wheel load of 10 000 kg. will be distributed over an area of at least 0.8 sq. m. Within this area a steel section of $2 \times 7 \times 2 = 28$ sq. cm. will be found, and the shear is $\frac{10\,000}{28} = 357$ kg. per sq. cm., which is far below the safe value.

Referring to the graphical computation by the aid of the diagram, Fig. 19, it is found that the moment, $M = 4 \times 93\,057 = 372\,228$ in-lb. is plotted in Part I of the diagram. Projecting this moment into Part II, to the lines, $d = 11$ and $d = 18.1$ in., corresponding to the two cases described; and again projecting these two sizes through Parts III and IV, as shown on the diagram, it is found at once that steel sections of 0.65 sq. in. and 0.37 sq. in. per foot of width are all that is required.

Example 2.—Another case, shown on the diagram, refers to an overhead bridge of 49.2 ft. span. The calculation is based on 15.8 m. (51.8 ft.) from center to center of bearings. This span exceeds the limits of the diagram, and, consequently, there is used $\frac{51.83}{3} = 17.28$ ft., and four-ninths of the moment of the allowable load, which corresponds to a factor of safety of four, and amounts to 625 600 in-lb. Projecting this size in Part II to the line of $d = \frac{31.89}{3} = 10.63$ in., there is obtained $C_s \zeta_s$ for Part III, and, finally, in Part IV, is found

*M. Koenen, "Regeln für die Anordnung der Eiseneinlagen in Betoneisenbauten," *Beton und Eisen*, No. 5, 1903.

†"Die Schubspannungen in Beton- und Betoneisentraegern," *Beton und Eisen*, No. 3, 1903.

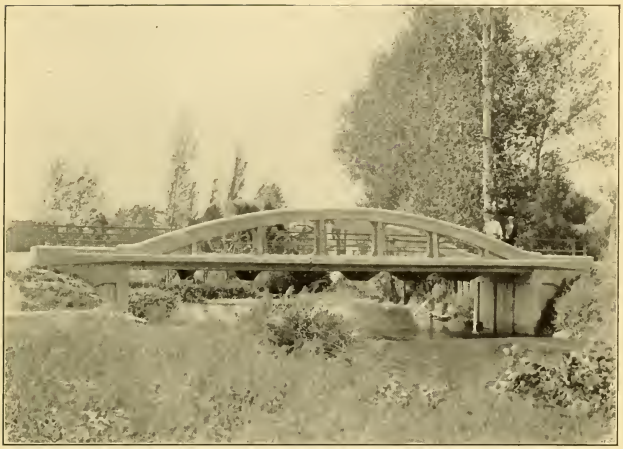


FIG. 1.—CONCRETE-STEEL BRIDGE OVER THE LARG, AT BRUENIGHOFEN, ALSACE.

FIG. 2.—CONCRETE-STEEL BRIDGE AT BAMBERG.

3.45 sq. in. per ft. of width as the reinforcing required. The total width of this bridge is 3.4 m. (11.15 ft.), which would correspond to $F_s = 248.4$ sq. cm. (38.5 sq. in.) while it actually contains $F_s = 290$ sq. cm. The disagreement is due to the use of a somewhat different allowable load and also a somewhat different method of computation, which is repeated in the following:

The upper portion is computed for a wheel load of 0.75 metric tons. Its total thickness is 18 cm.; $d = 16$ cm.; the dead load, 735 kg. per sq. m., and the greatest moment, for a width of 50 cm., is

$$M = 0.5\,\frac{735 \times 0.5^2}{10} + \frac{750 \times 0.5}{4} = 10\,294 \text{ kg-cm.}$$

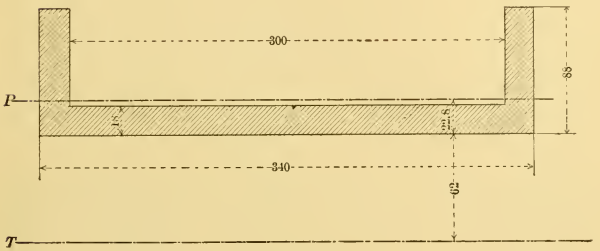


FIG. 20.

Using eight wires, of 6 mm. diameter, $F_s = 2.26$ sq. cm., $f_s = 0.022$ cm., $y = 13$ cm., $W_s = 1.13 \times 14.5 = 16.4$, and $\zeta_s = 650$ kg. per sq. cm.

The dead load on the beam is 76 500 kg., the live load at 340 kg. per sq. m. is 15 300, or a total of live and dead of 91 800 kg. Remembering that the span is 15.8 m., the greatest bending moment $= \frac{91\,800 \times 1\,580}{8} = 18\,132\,000$ kg-cm. The parapet which, as shown by Fig. 20, is of one piece with the beam, should also be included in the resistance of the latter. Determining the center of pressure of the concrete in compression, the distance between centers of compression

and tension is found to be $m = 84.8$ cm. Hence,

$$W_s = 290 \times 84.8 = 24\,592, \text{ and}$$

$$\zeta_s = \frac{18\,132\,000}{24\,592} = 737 \text{ kg. per sq. cm.}$$

The adhesive stress, calculated as in the foregoing, is

$$k = \frac{\delta\, S}{4\, M}\, \zeta_s = 1.6 \text{ kg. per sq. cm.}$$

and the longitudinal shearing stress $= 1.5\, \frac{S}{F_c} = 8.15$ kg. per sq. cm.

The latter stress exceeds safe allowable limits, and stirrups between the top plate and the tension rods are required. The computation of the section and number of the stirrups to be used is based on the assumption that, with 600 kg. per sq. cm. shearing stress in the steel, they should reduce the shear in the concrete to 6 kg. per sq. cm. Taking four stirrups of 1.2 sq. cm. area each in one section, the total stirrup area is 4.8 sq. cm. The shear in the concrete has been found to be 8.15, subtracting the allowable six, the shear to be taken up by the stirrups is 2.15 kg. per sq. cm. This gives a distance of 45 cm. from the bearing to the first stirrup, which distance will be increased toward the center of the span.

A design for the same case for a ready-made latticed beam of the Visintini system is shown in Fig. 21. The advantages of constructing reinforced concrete bridges without falsework and, consequently, without interfering with traffic, are apparent. Besides, such of the work as can be done without haste will be not only cheaper but also more reliable in its results. But of still greater advantage is the fact of enabling the engineer to specify that an additional number of full-sized beams shall be furnished, which will be tested to destruction, the acceptance of the lot being dependent on the good results of the tests.

Another example of a latticed concrete-steel bridge is the bridge over the Larg, at Bruenighofen, in Alsace, built by Ed. Züblin, Fig. 1, Plate XVIII.

The longest spans reached by girder bridges of reinforced concrete at this time are represented by a footbridge at Payerbach, of 85.3 ft. (26 m.) span, built by Ast and Company, of Vienna, and a bridge near Brançon, of 71.2 ft. (21.7 m.) span, built by Hennebique, Paris. Besides these two light bridges, there should be men-

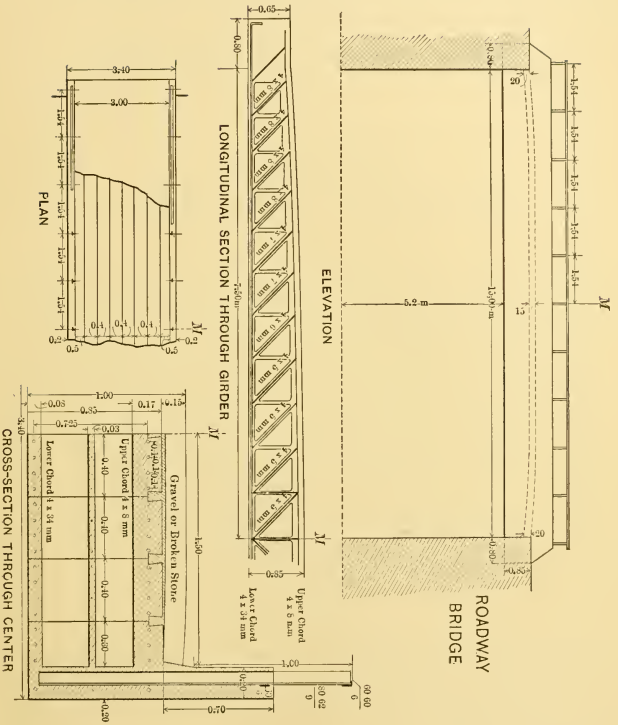

ROADWAY BRIDGE
ELEVATION
LONGITUDINAL SECTION THROUGH GIRDER
PLAN
CROSS-SECTION THROUGH CENTER
Gravel or Broken Stone
Upper Chord 4 x 8 mm
Lower Chord 4 x 34 mm

FIG. 21.

tioned a bridge at Bamberg of 65.6 ft. (20 m.) span, Fig. 2, Plate XVIII, designed by Luitpold and Company, of Stuttgart, and built by Dyckerhoff and Widmann. This bridge is 30 ft. wide, and was finished only recently. There is also a girder in the Moulin Rouge, Paris, of 65.6 ft. (20 m.) span, built by Hennebique, and carrying a wall, the load supported being 100 tons.

TRANSACTIONS
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DISCUSSION ON
CONCRETE AND CONCRETE-STEEL.

By Messrs. W. W. Christie, Albert W. Buel, R. J. Gifford Read, F. Schüle, Richard L. Humphrey, J. L. Van Ornum, Oswald Erlinghagen, Robert W. Lesley, Charles G. Darrach, A. N. Talbot, Gardner S. Williams, William B. Fuller, Rudolph P. Miller, Oscar Lowinson, G. N. Knapp, H. F. Dunham, E. P. Goodrich, J. B. Marsh, Augustus Smith, Frank Beckwith, W. K. Hatt, A. L. Johnson, Sanford E. Thompson, W. D. Pence, C. A. Wentworth, E. M. Scofield, Sidney B. Williamson, Edwin Thacher, John S. Sewell and Dr. Fritz von Emperger.

Mr. Christie.

W. W. Christie, M. Am. Soc. C. E., Paterson, N. J. (By letter.)—In addition to the tank or stand-pipe described on page 434 of Mr. Thacher's paper, there are in the same sedimentation reservoir two tanks, 16 ft. inside diameter by 17 ft. inside height, standing on four columns at the circumference. The top floor of the sedimentation reservoir is one monolith with circumference of these tanks. The sides of the tanks are 12 in. thick at the top and bottom, and both are reinforced with Ransome bars. The bottoms of the tanks are laid on beams monolithed with the columns. The columns are 3 by 4 ft. at the top and 4 by 7 ft. at the bottom and are about 25 ft. clear height.

Mr. Christie. Dr. von Emperger refers to a concrete monolithic chimney, 160 ft. high, in Ireland, which has withstood the heaviest storms.*

Sutcliffe† says the first example in England of concrete chimneys was at Sutherland; the foundation was of concrete 12 ft. square and 6 ft. thick. The chimney base was 24 ft. 9 in. high, 7½ ft. square outside and 4 ft. square inside, lined with fire-brick. Above the base was a moulding, 21 in. high, then an octagonal shaft, 30 ft. high, from 15 in. thick at the bottom to 9 in. thick at the top. For the base, the concrete was 1 part Portland cement to 8 parts shingle and sand; for the shaft, 1 part Portland cement to 5 parts gravel and sand. Rubble stones were packed in as the concrete was laid. The finishing coat was ¼ in. thick, composed of 1 to 1 cement and sand divided into ashlar.

Sutcliffe also refers to concrete chimneys having been built elsewhere before this one.

Another old chimney, though not of concrete, is interesting in this connection. It is built of stone laid in mortar, and is or was, in 1903, at Powers and Weightman's chemical works, near Philadelphia, Pa. As nearly as the writer recalls, the height is 90 ft., the flue, 6 ft. inside diameter, and the walls are 3 ft. thick at the bottom.

In Italy and Switzerland chimneys have been successfully built of concrete.

"The exterior mantel or shell of the chimney is formed of insetted, or armed cement prisms, joined by cement mortar. The base is so constructed that to avoid cracks in the outer shell the cool air may enter from without and pass between the shell and the core. The dimensions of the cement blocks are about 0.25 × 0.20 × 0.15-meter, and vary with the general dimensions of different chimneys."‡

This type of chimney is planned with an ornamental top, monolithic with the outer shell and independent of the core.

A concrete-steel dust flue having a cross-sectional area of 126 sq. ft. was built for the Arkansas Valley Smelting Company at Leadville, Colo.§ The concrete used was 1 part German Portland cement to 3 parts sand, for all except the crown, where furnace slag was substituted for the sand. The concrete was reinforced with expanded metal.

In addition to the reinforced concrete chimneys referred to by Mr. Thacher, we find two at South Bend, Ill., built for the Singer Manufacturing Company, 130 ft. high and having a flue, 6 ft. in diameter.

* *Transactions*, Am. Soc. C. E., Vol. XXXI., p. 451.

† "Concrete, Its Nature and Uses," 1893.

‡ *Engineering News*, September 19th, 1901.

§ "Chimney Design and Theory," by W. W. Christie, p. 146.

Mr. Christie.

One at Milwaukee, Wis., illustrated in Ransome's "Catalogue" for 1904.

The Los Angeles chimney is also well illustrated in the same catalogue.

The Singer Manufacturing Company, at Elizabethport, has a straight chimney, 125 ft. high, with a flue 9 ft. inside diameter. It weighs 250 tons, the load on the base being $9\frac{1}{2}$ tons per sq. ft.; 20 lb. per ft. was allowed for wind pressure in designing the chimney. This the writer believes to be too little.

What is known as "wet concrete," one which quakes slightly when rammed, was used, mixed as follows: 1 part American Portland cement, 3 parts sand, 5 parts broken Hudson River limestone, such as would pass through a $\frac{3}{4}$-in. ring unscreened. All concrete was machine mixed.

What the writer would consider the highest concrete and steel chimney in the world is that of the Plymouth Cordage Company, at Elizabethport, N. J., which is 220 ft. high with flue $8\frac{3}{4}$ ft. inside diameter.

Mr Buel.

ALBERT W. BUEL, ESQ., New York City.* (By letter.)—Mr. Thacher's paper is a valuable contribution to the literature on the subject, and covers the field so thoroughly and fairly that there does not appear to be much to add in the way of discussion.

Mr. Thacher sees "no good reason why concrete-steel spans of 500 ft., or more, cannot be built with perfect safety." The writer had the honor to assist William H. Burr, M. Am. Soc. C. E., in the preparation of his designs for the Memorial Bridge at Washington, one of which was awarded the first premium. In the course of this work, it was found that a span of 283 ft. could not be built with an elliptical intrados, having a less rise than one in four, without exceeding the allowed unit compressive stress in the concrete. This indicates that the longest span which can be built with the unit stresses now customary is from 400 to 450 ft.

The point brought out by Mr. Thacher that, in Europe, concrete arches are all built with hinges, while, in America, they are all fixed arches, brings up the question of the relation of hinges to the shape or form of the ring, which does not seem to have been generally understood nor appreciated. Segmental arches, of any considerable length of span, should have either two or three hinges to avoid tension at and near the springing. Hinged arches should always be segmental, for economy in design, as there is, theoretically, no moment at the hinges.

The success or failure of concrete, and especially reinforced concrete, is so largely dependent upon the manner of executing the work, and the difference between good and poor work is so great

* Engr. of Bridges, Western Maryland R. R.

Mr. Buel. that too much emphasis cannot be given to the importance of securing a higher grade of supervision and more of it than is customary for the general run of engineering works.

Mr. Read. R. J. Gifford Read, Assoc. M. Inst. C. E., London, England.—It is only within the last few years that concrete and steel have been used to any extent in England. The speaker's early experience was with ordinary concrete, reinforced with layers of expanded metal, for distributing heavy floor loads on soft ground, also with superior concrete interwoven with small iron rods for thin floors in warehouses, similar in principle to the Monier system. But the system which has recently made the most headway in England is that patented by M. Hennebique, of Paris, and its progress is due, in a great measure, to the skill and enterprise of Mr. Mouchel, agent for the system in London.

The name commonly used for the combination is "ferro-concrete," and as such the speaker will term it in his subsequent remarks.

Having heard that piles had been made of this material and driven, the speaker was induced to try it in a case where the foundations of a building, which had been constructed on timber piles, had settled and cracked the walls, owing to the timber having been eaten through and destroyed by the larvæ of a certain beetle. In extending the building, therefore, ferro-concrete piles were used and driven about 30 ft. deep through peat and clay into gravel. On top of these, sills were formed of the same material, which carried the brick walls of the building. Since then the speaker has adopted it for the foundation of a warehouse to carry heavy loads on very bad ground near the River Thames, and in this case he first consolidated the ground by covering it with a layer of dry brick rubbish, well rammed, and then placing over the whole area a slab of ferro-concrete stiffened under the walls and pillars with ribs of the same material, as would be done if it were being made of a large cast-iron plate. The warehouse was built upon it, and the ground floor was used for stacking tin plates, the weight of which sometimes amounted to 15 cwt. per sq. ft., and so far it has stood very well.

Another work in which the speaker is now using this material is the construction of a water tank, 70 ft. in diameter and 12 ft. deep, on pillars about 60 ft. high. As it is only just commenced, he cannot yet speak of it as a success, and there are many points in connection with it about which he hopes to obtain information. For instance, the connection of several members at a certain point required careful consideration, as the space occupied by the intersection of the steel rods was so great as to leave very little room for the concrete to be rammed between them, and it was sometimes

advisable to eliminate certain members, or divert them from the true line of intersection in order to make sufficient room for the bars of the others to be embedded properly in the concrete. Mr. Read.

In reference to this, some interesting statements as to the adhesion of concrete to iron rods have been made. The speaker has been accustomed to consider the adhesion of a plain round steel rod, 1 in. in diameter, to be equal to the strength of the rod when it was embedded 30 times its diameter in the concrete, but he would be glad of further information on this point.

There is a great field open for this material in fireproof construction, but for that purpose it is not advisable to use limestone in its composition. Concrete is a bad conductor and transmits heat slowly, consequently it takes a long time for the iron rods in a beam to feel the effect of heat from the outside, and when they do get heated up they are not capable of wrecking a building to the same extent as large iron girders and joists do when they expand.

The writer does not consider a ½-in. thickness of covering sufficient for the protection of ironwork against fire. At present the Building Act of London is very much against the economical use of ferro-concrete for buildings, as it will not allow the outer walls between piers to be reduced in thickness below that prescribed for the old style of building. This, however, is expected to be altered soon.

F. Schüle, Esq., Zurich, Switzerland.—The different papers on "Concrete and Concrete-Steel" cover the subject so well that it is only necessary to discuss some of the more important points. Among these the speaker will mention first the question, always very obscure, of cracks which appear in concrete-steel exposed to the air. Public security can be endangered by the appearance of these cracks in the weakest parts of this construction in one or two years after it is finished. Their origin is, for the greater part, due to the variation of volume of concrete exposed to the air. It would be very useful to discover by special research the laws regulating their appearance; such research, however, is more the work of a physical laboratory than that of a material-testing laboratory. Mr. Schüle.

The confidence of the public in concrete-steel construction will depend on the quality of the materials used and the quality of the work done; one very important factor of security is the excellent quality of Portland cement manufactured to-day. The work in the construction itself can and must be controlled by testing the concrete in form of cubes (compression test), or prisms (bending and compression test). The control would be simplified by using special systems of concrete-steel such as the Siegwart beams made in a shop outside of the building and with special machines, thus securing a very uniform material.

The *Schweizerische Bauzeitung* for August, 1904, gives the re-

Mr. Schüle. sults of comparative tests of two series of Siegwart beams, showing the difference between the elastic and permanent deflections up to rupture of the beams. These tests were made at the Testing Laboratory of the Federal Polytechnic Institute of Zurich with a machine for bending tests. In regard to the important point of the first cracks in beams by bending tests it might also be of some interest to mention the tests made at the previously mentioned laboratory in 1900-04. It was found difficult to find the first cracks, and it was necessary to paint the lateral faces of the beams with gypsum. The beams were of rectangular section 20 by 30 cm., the length between the supports being 1.50 m.; some beams were without steel bars and others had steel bars of different sections. In the first series, the load was applied in the middle of the beams, in the second, at two points in the middle, 30 cm. apart. On this length of 30 cm., the bending moment was constant. The concrete beams which had not been reinforced broke under a total load of 1.90, 2.88 and 3.06 tons in the first series, and 2.5 and 2.7 tons in the second series. The reinforced beams showed the first cracks under a load of 5.5 tons in the first series, and of 4, 4.5, 7 and 7 tons in the second series. With two different sections of steel bars and the increasing load, these beams reached a maximum of 14.3 and 16.5 tons in the first series, and 17.5, 20.9, 30 and 31.4 tons in the second series. It seems that the presence of steel bars secures a better distribution of the internal stresses without changing the properties of the concrete. The latest experiments in Switzerland have not quite confirmed the statement of M. Considère as to the effects of steel bars.

With regard to the question of stresses in steel bars, the speaker can state that in the experiments at Zurich the direct elongation of the steel bars was measured from the beginning of the test, so that every time after increasing the load of 0.5 tons, we came back to the first load. The elongation of the bar was found both with the higher and lower loads. As concrete is not an elastic material and shows permanent elongation from the beginning, it was found that by reducing the load to the lowest point the elongation of the bars was not reduced to zero, but remains an elongation, and, consequently, a stress in the steel. When the elastic limit of the steel was reached, we found that there was no great difference between the increase of the stress and the increase of the load, both being proportional. Before reaching the elastic limit of the steel, the increase in the stresses in the steel bar was not proportional to the load, but greater, and the permanent stresses increased also by the addition of the higher load.

The question of testing concrete-steel construction is a very important one on the European Continent. The test is often made by

measuring the deflection after loading a floor, but the maximum deflection does not give a good result by which to judge of the strength of the floor. It was found to be much better to have a load which is not too great, but to have exact instruments to measure the deflection under half load, and under full load, after removing the half load, and, after removing the full load, to obtain in this way the increase and decrease of deflection, and the permanent deflection after the test. Mr. Schüle.

An important difference exists between European and American construction in concrete-steel; in Europe, the armature bars generally have a constant section and a smooth surface; in the United States, the bars used have variable forms of section. It seems that tests give a greater strength with beams having bars of the American type. The difference practically cannot be very great, because adhesion between steel and concrete is ended when the elastic limit of the metal is reached. Bars with a constant form of section will slide if their ends are not fastened; the other types of bars cannot slide suddenly, and the concrete will give some resistance against sliding.

The construction of concrete-steel tanks has been mentioned. It will be interesting to state that in Switzerland we have concrete-steel gas tanks of very large proportions. Maillart and Company, of Zurich, have built in St. Gall two gas tanks, 40 m. in diameter and about 9 m. high, holding about 10 000 cu. m. The results obtained with these concrete-steel constructions are good.

Richard L. Humphrey, M. Am. Soc. C. E., Philadelphia, Pa.— Mr. Humphrey.
In the earlier part of the discussion, the question was raised as to which term was proper, "concrete-steel" or "reinforced concrete," and there was some attempt made to justify both terms.

Some of the earliest constructions in concrete (and some of the present systems) consisted of a skeleton or framework of steel (of sufficient strength to carry the load) encased in a mass of concrete which protected the steel from the action of those forces of Nature which would accomplish its ultimate destruction. Such structures could very properly be designated by the term, "steel concrete" or "concrete-steel," inasmuch as they consisted of large masses of concrete and steel, and since, also, the concrete was not calculated to sustain any portion of the load, but was used simply as a protective covering for the steel.

The present practice in the design of structures of this character is to use the concrete as the principal material. But since it has little tensile strength, steel, usually in the form of bars, is introduced in sufficient quantity to carry the tensile stresses. To such structures, the term, "reinforced concrete," very properly applies.

Mr. Humphrey. The term, "steel reinforced concrete," might possibly be more suggestive and would cover the objection raised by Mr. Thacher, *viz.*, that concrete which was propped up with timber could be called "reinforced concrete." The speaker is of the opinion, however, that the term, "reinforced concrete," is sufficiently clear, and there can be no practical doubt as to its true meaning.

The term, loam, is a much abused one and is rarely used correctly. Loam, generally speaking, means earth or vegetable mould composed largely or entirely of organic matter, and is detrimental to the strength of cement, mortar or concrete, the reason being that this exceedingly fine material fills the pores in the surface of the sand, gravel, stone or steel, thereby preventing the cement from flowing in, and thus reducing the bond. The very finely divided material found in sand or gravel is not "loam" or organic matter, but inorganic matter consisting of the more finely divided particles of the sand or gravel. Excessive quantities of this material are equally as injurious as "loam" properly so-called. The percentage of this material which remains on top of the sand or gravel after agitation with water in a long cylindrical graduate (generally called "loam," but which should be designated as silt) should never exceed 5 or 6 per cent.

A number of papers have appeared recently in which the writers, in reporting the results of their experiments, have stated that "loam" up to 15% was found not to be injurious. As there was no definition of what the term, "loam," implied, no accurate idea could be formed as to the nature of these tests.

The fine sand or gravel which would pass a No. 100 or a No. 200 sieve, and which contains only a small percentage of silt, considerably increases the strength and density of mortar or concrete. The reason for which is found in the principle of sand cement; the finer particles fill the voids of the larger, thereby reducing the voids to be filled with cement and increasing the value of the cement. Theoretically the cement to have a maximum value should just coat the particles that it binds together, and any cement which is required to fill the voids is wasted. The perfect concrete is that in which the aggregates are so proportioned as to fill the voids completely to the smallest particles; in such a concrete, the function of the cement is to form a coating or film around each particle, which, in hardening, binds the whole mass together.

As to the remarks of Mr. Darrach regarding the advisability of using concrete in freezing weather, the speaker would state that the injury to concrete results from the alternate freezing and thawing which gradually destroys the bond of the partially hardened cement. This is particularly true in this climate, where extremes in temperature are the rule, the fluctuations being above and below the freezing point.

Mr. Humphrey.

The hardening of cement is a process of crystallization, and requires time for the development of strength. The freezing of water, whether of that added in mixing or that subsequently absorbed, is accompanied by expansion. The water, being confined in the voids in the sand, gravel and stone, which is bound together by cement, cannot increase in volume without disrupting the mass. This action is greatest in the earliest stages of hardening, when the mortar or concrete is green and before it has acquired any considerable strength. Even after the cement has acquired some strength, the alternate freezing and thawing may gradually destroy the bond of the cement. If, however, the temperature remains uniformly below freezing point, the chemical reactions take place, and, being undisturbed, the hardening is a continuous process; after a time, the water enters into combination with the cement, and the only danger from a freezing temperature comes from the water which is absorbed, and such action will occur on the surface only.

The speaker's remarks apply to Portland cement, which in its hardened form thoroughly resists the action of frost. Natural cement does not possess this property and is always affected to a greater or less extent by the action of frost.

A feature in connection with the permeability of concrete which has not been touched upon is the proportion of sand or gravel and stone in the mixture. Engineers are too prone to use a stated mixture without regard to the voids. A more intelligent use of the aggregates would be to determine the voids in the sand, gravel or stone, and from the results to fix the proportions in which they should be used. Such determinations often result in the use of a minimum amount of cement, and when the materials are thus properly proportioned, the voids are all filled, and the result is a minimum degree of porosity and permeability.

Dry mixtures produce porous concretes, which have great permeability. Wet mixtures compact more easily, yielding a far denser mass and consequently less permeability. Therefore, a wet concrete, which is properly proportioned as to the aggregates, has its voids completely filled, and the result is a mass of maximum density and minimum permeability.

The tests which have been made to determine the adhesive strength of cement have rarely extended over a longer period of time than one year, a time utterly insufficient to develop the true adhesive properties. While it is true that the coefficient of expansion of concrete and steel may be the same, nevertheless the expansion of a bar of steel and the concrete in which it is embedded, and of whose mass it forms a very small percentage, must be unequal, and the slightest difference in the movement of the two masses would be sufficient to break the bond between them.

Mr. Humphrey. The adhesion between cement and steel is a physical and chemical phenomenon. The cement in its plastic state flows into the pores of the material with which it is brought into contact, and, in setting or hardening, clinches or binds the mass together. The expansion and contraction due to temperature gradually break these bonds. This is a slow process, requiring a number of years to develop the maximum effect, and after an interval of ten or more years, there is likely to be little bond between them. In the speaker's judgment, no allowance should be made for adhesion.

Another subject which has received little or no consideration is the shrinkage of concrete. In inspecting a number of concrete walls during a period of ten or more years, it was noticeable that while these walls remain smooth and monolithic in appearance for several years after construction, fine hair-line cracks gradually develop in the surface, becoming more intensified by the accumulation of the salts of lime in the cracks.

The cracks appeared at the junction of one day's work with another, and, where the concrete had been deposited in layers, they appeared at the junction of the layers, showing a complete break in the bond between the layers. The speaker does not believe it possible to obtain a monolith by any other process than that of depositing the concrete continuously.

The large cracks which appear in concrete are due to structural weaknesses and usually appear at an early period. Shrinkage cracks also result from too rich mixtures, that is, mixtures containing too large a proportion of cement. Too rapid drying out of the water will produce shrinkage cracks in smooth-finished surfaces, which are quite noticeable in wet weather. In sidewalk work, these cracks are present, but are concealed by the fine dust which is ground into them by the feet of pedestrians.

As to the question of limestone used in concrete, the speaker would remark that it seems to him that undue importance is attached to its possible weakness, in case of fire, from calcination. In most concrete work it is generally the practice to keep the stone back from the face, and this insures a coating of mortar over the face of the stone, thus sealing it from the action of the fire, and preventing the calcining action. Again, it should be noted that only the surface of the stone would be acted upon by the fire, and the process of eating into the mass would be, therefore, quite slow.

Slag concrete is dependent for its goodness on the quality and character of the slag. Basic slag is soft and friable and wholly unsuited for use in concrete. Acid slag is generally used, and to be of first-class quality must be hard and dense, and free from sulphides. Such slag is difficult to obtain; the general specification of slag without governing restrictions and careful inspection is a bad practice.

Mr. Humphrey.

The use of cinders in concrete is also inadvisable; not only on account of the difficulty of securing suitable cinders, but also from their low compressive strengths.

The strength of concrete depends on the strength of the material of which it is composed. Cement cannot augment the compressive resistance of the materials which it binds together. Ordinary boiler ashes or cinders have low compressive strength, and the speaker's experience shows such concrete to have an average compressive strength of less than one-half of that of gravel or broken-stone concrete, even if the cinders are of first-class quality.

Cinders often contain considerable quantities of sulphides and fine ashes which tend to destroy the strength of the concrete in which they are used. Cinders of good quality make a concrete light in weight, and for this reason are extensively used in fire-proof floors. As in the case of slag, the use of cinders is to be discouraged and wherever specified should be subjected to rigid inspection before permitting their use.

Prof. Van Ornum.

J. L. Van Ornum, M. Am. Soc. C. E., St. Louis, Mo.—The speaker believes that Captain Sewell's practice of using a factor of safety of $2\frac{1}{2}$ (designed to stress the steel to its elastic limit and the concrete to its ultimate compressive strength) is the lowest value that engineers can use with due regard to their reputations and to the safety of the structure. It is a well-known fact that test specimens of concrete, made and treated identically in every way, will show variations in strength up to 15%, or sometimes more, from the average value; and no doubt differences of material or treatment in construction, which are less capable of control under these conditions, will cause variations in strength at least as great. Furthermore, the speaker's tests upon the "fatigue" of concrete and armored concrete have been carried far enough at this time to prove definitely the fact that repeated applications of a load will cause failure where the intensity of load is more than about 50% of the ultimate strength of the specimen; below this value, repetitions seem to have no destructive effect. If now, a certain portion of the structure happens to be 20% weaker than its assumed strength, and the question of its ability to withstand repeated applications of the live load is also considered, it will be seen that the actual strength of the concrete is little greater than that necessary to resist indefinitely its maximum loading; or, in other words, that the factor of safety has almost disappeared in providing for those variations and conditions whose existence make necessary the use of a factor of safety in all design. The speaker, therefore, is strongly of the opinion that the value of the factor of safety mentioned should never be reduced, and that it may be safely used where inspection and workmanship are faithfully executed.

Prof. Van Ornum.

While Captain Sewell's assumption that there are no initial stresses due to change of volume of the concrete in setting is, as he says, probably safe for ordinary conditions of construction, it would seem proper to add a word of caution for the unusual case. Whenever moist conditions predominate for a week or two after the concrete is placed, as Considère shows, an initial tension is induced in the steel that may seriously encroach upon the strength that is otherwise depended upon for structural purposes. Again, under similar conditions, and where steel reinforcement is not introduced in a way to assist in the transfer of the increment of stress to the steel, the adhesion of the concrete to the steel bars is reduced to a point that may be dangerous. During the past winter, tests were made in the Washington University Testing Laboratory, of the adhesion of concrete to steel, which gave values less than one-half those usually accepted. These specimens were kept in water for two weeks after being made, and tested after standing in air for an equal length of time. There are other records of a similar low adhesive strength. The speaker believes the great difference in adhesive value to be due mainly to the fact that the hardening of the specimens in the presence of moisture expands the concrete and so reduces the bond.

In speaking of the reinforced concrete piles at Washington Barracks, Captain Sewell states that they "were reinforced against flexure by means of a single, central longitudinal steel rod." The speaker is puzzled to see how a rod so placed would have any potency. Would it not be as valueless to resist flexure as the reinforcement of a beam, if placed horizontally through the center of the beam?

Mr. Erlinghagen.

Oswald Erlinghagen, Esq., Remscheid, Germany.—The question as to the quantity of water necessary for the proper mixture of concrete is not yet entirely settled, some preferring the "earth-wed" and others the "plastic" mixture. Tests have shown further that there is a great difference in the strength of concrete mixed in a machine and in that mixed by hand. There are no standard specifications for the testing of concrete, as yet, in Germany.

The speaker is surprised to know that in the United States the testing of the strength of concrete is practically limited to tests of the tensile strength. In Germany, great importance is laid on the strength in compression, to which concrete and concrete-steel structures particularly are subjected. The speaker thinks that in the United States, engineers are afraid to procure the proper testing machines, which may be expensive. Therefore, he would like to mention that Professor Martens, Grosslichterfelde, Germany, of the Königliche Material-Prüfungsamt, built a simple machine for testing the compressible strength of cement and concrete. As far as the speaker knows this machine in practise is used for pressures of about 88 200, 110 200, 661 500 and 882 000 lb.

Mr. Erlinghagen.

The speaker desires to call the attention of this Congress also to the difference of opinion between Professor von Bach of Stuttgart, Germany, and Professor Föppl of München. These gentlemen do not agree as to the methods of testing the tensile strength of cement and concrete. Professor Föppl states that the bending tests, modified by certain coefficients, furnish the proper figures, while Professor von Bach says that this method is altogether wrong, and that the real tensile strength of test pieces may be obtained only by the direct tensile tests. An unprejudiced engineer probably would prefer the latter method.

There are two properties which are of especial importance in the calculations for concrete-steel, namely, the elastic limit of the concrete and the adhesion between the concrete and the steel bars. These two properties differ very much according to the quality and quantity of the different materials which are used; they differ even in test pieces of concrete of the same mixture.

In Germany, among others, the Deutsche Beton Verein is endeavoring to furnish standard specifications and to settle the matter by thorough experiments and has invested a large amount of money for this purpose.

Meanwhile, the Prussian Minister of Public Works, in May, 1904, issued a statement about the workmanship of concrete-steel structures in the building trade. These specifications contain rules about the testing, workmanship and inspection of these structures, and give valuable *Leitsätze* or hints for the calculation of concrete-steel buildings. The elastic limit of the steel is assumed to be fifteen times the limit for concrete, if this proportion is not fixed by special tests. The adhesion between the steel bars and the concrete is assumed to be not more than 64 lb. per sq. in.

Some of the best known German civil engineers of the older school, but who have had great experience, do not like the concrete-steel structures for places where they are exposed to the weather. The evil begins with those small cracks, "hair-fissures," into which small quantities of water penetrate; if these are not attended to, the structure will soon show greater cracks, and we must do our best to avoid them by the application of good material, good workmanship, and proper designing, in which the stresses of the structure are calculated exactly. The bad effect of these small fissures might be eliminated by proper painting.

Mr. Lesley.

Robert W. Lesley, Assoc. Am. Soc. C. E., Philadelphia, Pa.— The question of the freezing of mortars has been discussed, and there is no doubt that mortars can be preserved, during great frosts and very cold weather, by means similar to those described by Mr. Darrach. The more continuous the cold weather, the better the concrete will be. Many years ago, in the early days, some experiments

Mr. Lesley. were made to discover what happened in the freezing of the mortar. These experiments were made under Colonel Douglass, then Chief Engineer of the Baltimore and Ohio Railroad, and Colonel Patton, who had charge of the construction of the bridge over the Schuylkill River, at Philadelphia. The experiments showed that a mortar which was placed in the coldest weather and allowed to freeze continuously and which was then brought into a heated room, would thaw out and lose its set and then set again. They developed the further fact that mortars that were put out and brought in alternately day by day for a period of three or four weeks would lose their strength according to the number of alternations in temperature. Now that series of experiments was very fully carried out for those times. The speaker does not believe that it has been published. It showed that while the entire body of mortar was not affected by these changes in temperature, a considerable portion of the exterior was.

From examinations made at that time and subsequently, and from observations of what happened under the conditions referred to above, it strikes the speaker that the first action of a mortar when made in any weather is to try to set. Each little particle of lime, silica, etc., tries to get together and set, even in the coldest weather; this is the chemical action. Then comes another powerful element—Nature—which sets up a freezing condition, and every bit of water is made immediately into little globules, and while every particle of water is not taken from the cement, a large percentage of it does become frozen in that mortar. This stops the chemical action by depriving the cement of water. After a while, warmer conditions return, Nature releases her hold of the water; chemical action takes place, and the setting goes on. This might be called the second set of a cement. Now if one goes on making two, three, four or five sets, one will weaken the quality of the material more or less, as every man knows who has made briquettes. There is no doubt of what Mr. Darrach thoroughly describes as a moment of suspension when the mortar is first exposed to frost, and there is a great and, no doubt, a permanent benefit in having the water, the sand, the concrete and surroundings hot, so as to permit an immediate setting. Undoubtedly that is the way to make concrete in cold weather, for the reason that hot weather promotes chemical action, which is setting, and cold weather retards it. If, therefore, the concrete is kept in a favorable condition of temperature at the time the concrete is setting, so that Mr. Chemistry will beat Mr. Jack Frost, a good concrete will be the result. The more it is possible to keep this condition during the setting time, the better the mortar will be.

Another series of experiments on the results of alternating the exposure of mortars to frost and heat has been made by W. A.

Aiken, M. Am. Soc. C. E., Chief Inspector of the New York Rapid Transit Commission, at the testing bureau at Egypt, Penna., where results similar to those described above have been obtained. Mr. Lesley.

In the line of protection of concrete during freezing, a recent number of the *Railroad Gazette* has the following:

"One point which does not yet seem to be satisfactorily established is the effect of freezing concrete before the final set has taken place. Some specifications require that no concrete shall be placed during freezing weather, and, on the other hand, some of the most extensive pieces of concrete work in this country have been carried out and completed during severe winter weather. Neat cement will take an intial set after about half an hour, but the final set does not take place until after from thirty to sixty days' exposure. The water which is added in the mixing brings about the first chemical combination of the particles which gives the cement its intial set. If this action is arrested by freezing, the mixture remains inert until thawed out, when the chemical action again begins. Numerous tests have been made to determine the effect of freezing and thawing, but unfortunately there is still a wide divergence of opinion. Mr. Campbell states that tests made during the progress of the work on the St. Louis, Kansas City and Colorado showed that freezing resulted in a loss of strength and that salt was worse than useless as an ingredient of the mixture to prevent it, since it takes place only at temperatures below which a salt solution will freeze. The only satisfactory method of placing concrete in winter weather, which appears to have been tried to any extent, is heating the ingredients, before mixing, in stoves and placing the concrete while still hot. If the mass is large enough and is covered by straw or some other frost-proof covering, enough heat is retained to prevent freezing until after the water in the mixture has combined with the cement as water of combination. After this there is little damage to the concrete by exposure to freezing temperatures, and work carried out in this manner during the coldest weather has not yet developed any serious defects. There is need of a reliable series of tests and experiments made under actual service conditions and in the laboratory, to determine the effect of freezing temperatures on large and small bodies of concrete."

Now, as to the question of fire-proofing. The speaker has the honor of being a member of the Committee on Concrete and Reinforced Concrete of the American Society of Civil Engineers, and has, together with other members of that Committee, given a great deal of thought to this subject. The question of fire-proofing is a vital one. We all know that it is possible to figure on the iron or steel, the character of the reinforcement, the adhesion, and the number of elements entering into the reinforced concrete construction; but when it comes to making a fire-proof building, there has been little or nothing written as to the kind of stone to be used as the basis of the concrete. Cement seems to be a well-known material; iron and steel are equally well known, but little is known of the sand and

Mr. Lesley. stone which go to make up the concrete. Now, let us imagine for a moment, a narrow 12-story building in the dry-goods district of a large city, built of a concrete made of Natural cement. This cement is calcined at temperatures of under 2 000°, or below the fire limit. Let the aggregate of that concrete be a limestone, which will give up its carbonic acid gas at temperatures of 1 500° to 1 800°, still below the fire-station experiment limit; fill that building with combustible merchandise, desks, dry-goods, etc., on each floor, and start a fire at the bottom. Does it strike any one that the construction bears a remarkable likeness to a lime-kiln? It has height, draft and layers of limestone and is combustible. It is needless to say that a fire getting a proper headway in a building of this kind would turn the limestone into lime by driving out the carbonic acid gas, and it would also drive out any excess carbonic acid gas from the Natural cement.

After the fire has gotten thoroughly under way, it can be readily seen that the floors of the building, if it were built of beams and girders of similar material, would all be turned into lime, and let any one turn water on the lime thus produced, the result of the experiment can be imagined. There will be a large mass of slaked lime which will give way, and the building is likely to fall.

There are many places in the United States where limestone is the building stone easiest to be had. The speaker knows that we are at the beginning of a new field of construction, but he feels, in fairness to that construction and in fairness to those who are likely to stake their success on the result of it, that the sand and stone which enter into its composition should have full consideration, otherwise there are likely to be great losses where reliance has been placed upon the fire-proof qualities of a material that is not fire-proof. Of course, the danger of this use of limestone would apply only to the fire-proof construction, because for arches, bridges, etc., limestone makes as good concrete as any material.

A small percentage of lime would not be as bad as a limestone, but it seems to the speaker, as a broad proposition, that igneous rocks, or rocks that have been through the fire, such as trap-rock, should be used where fire-proof construction is desired.

While this is the sad side of the subject, the actual use of concrete construction has its happy side. In Belgium, not long ago, there was a silk mill—a small building—built under the guaranty of one of the reinforced concrete construction companies that it would stand for a certain number of years and show no diminution in strength. There were full tests made, and the guaranties upon the acceptance of the building by the owner were fully met. There was a fire in the building a couple of years later, and after the smoke cleared away, it was found that the building was not

damaged; that the shafting showed no signs of distortion, and after a couple of days of cleaning, the mill was ready for work. Most people would have been satisfied under these circumstances, but in this case, the manufacturer, who was a Belgian, and wanted everything done properly, insisted that there should be another inspection by the construction company, so that the guaranty would still be binding. The inspection was made, and the floors showed an increased strength of from 600 to 900 kg., as compared with the first test; in other words, the building was stronger after the fire than it was before. Mr. Lesley.

CHARLES G. DARRACH, M. AM. SOC. C. E., Philadelphia, Pa.—In the earliest experience of the speaker, some thirty-eight years ago, he was called upon to use cement and concrete, and since that time he has been what you might call a devotee of concrete construction. It so happened that at the Annual Convention of the American Society of Civil Engineers at Washington, in 1902, he was selected to be the leader in the discussion as to which of the two, metallic or masonry, constructions, was the better. At that time, the use of reinforced concrete was practically in its infancy, or unknown in the United States. The discussion* may be of interest to those who have not already read it. Since then the speaker has been the engineer of the mechanical plant in a building in Philadelphia for the gymnasium of the University of Pennsylvania. This building is constructed entirely of reinforced concrete except the exterior walls, which are faced with brick, but unfortunately, the trimmings are of terra cotta. This building is exceedingly interesting and instructive, in that it is constructed upon concrete piers reaching to a depth of 40 ft. to solid rock through filled materials of all kinds. In this building, there is a swimming pool, 100 ft. in length, 30 ft. wide and 8 ft. deep. If we were to excavate through the materials under and around this building and swimming pool, we would have a structure in which would be found a tank containing 144 000 gal. of water, 3 000 sq. ft. in area, supported on piers, 40 ft. high. Three sides of this tank, having an area of about 130 000 sq. ft., are exposed in the engine room of the building, and the walls, which are about 2 ft. thick, are not only water-tight, but absolutely damp proof. The concrete was not constructed as a water-tight concrete, the interior of the pool being lined with $\frac{1}{2}$ in. of asphalt, upon which is laid enamel brick. This building was built through the winter of 1903-04, and there were some cracks developed in the floors, apparently surface cracks, which need not have occurred if the blocks forming the floors had been divided.† Mr. Darrach.

* *Transactions*, Am. Soc. C. E., Vol. XLIX, p. 71.

† The architects of the gymnasium for the University of Pennsylvania were Frank Miles Day and Brother, Philadelphia.

Mr. Darrach. During the past year the speaker was engaged in the northwestern part of Vermont, where a minimum temperature of 56° fahr. below zero was reached, and during a period of from thirty to forty days, the temperature did not rise, as an average, to 10° below zero at eight o'clock in the morning. Many days it was 30° below zero, but notwithstanding this extreme temperature work was not stopped one day on account of the weather. The experience was novel, but the employment of about 150 men, and the large amount of capital involved, put us, as we say, "up against it." The specifications and requirements demanded that concrete work should not be constructed in freezing weather, to follow which would have involved loss, not only in the capital lying idle and already expended, but also in the loss of time. Fortunately a bed of sand was found within a mile of the work. It was very sharp and so beautifully graded that the voids were only 20 per cent. The specifications under which we worked were 1:3:6. The stone was a very fine conglomerate, almost like sandstone, and very hard. The stones were broken so that the largest would go through a 1½-in. ring, and graded down to the finest, with little dust. A "Smith" concrete mixer driven by a steam engine was used.

A large water tank was erected on trestles sufficiently high to allow the water to flow to the mixer through a hose. The temperature of the water in the tank was raised from about 120° to 140° fahr. by live steam, but after the engine was in commission this temperature was maintained by the exhaust from the engine driving the mixer. The sand and broken stone were kept under cover, and the initial frost removed by light wood fires. The cement and sand were first put in the mixer and thoroughly mixed to a uniform color. The hot water and broken stone were then added. The concrete was placed in the derrick buckets swimming wet and immediately dumped into the forms. It was so fluid that the men stood in it with gum boots on and worked it into all parts of the forms with spades and tramping. The temperature of the concrete when first put into the forms rarely fell below 70° fahr., and was frequently as high as 90° fahr.

The form of construction was particularly difficult for cold weather, being an arch 12 to 18 in. in depth, and the piers supporting the arch were about 2 ft. wide on top and 3 ft. wide at the bottom. So that the ordinary methods of construction in that extraordinary weather would not have been possible.

Instead of using reinforcement of rods, the speaker used pipes, properly drained and supplied with steam, consequently we had summer all the time. When we stopped work at night we simply laid some few temporary pipes on the surface and covered them with tarpaulin or paper and boards, and as a result a piece of concrete,

several pieces of concrete in fact, which were broken, showed that the adhesion of the cement to the stone was greater and stronger than the cohesion of the stones themselves. The pipes were 1 in. in diameter and were used in all concrete work, whether required for reinforcement or not. In this connection may not the question be asked: Is it not better to use pipe for all reinforced concrete work, thereby getting the maximum surface for adhesion, as compared with the metallic section? Mr. Darrach.

The speaker cannot allow one statement which Mr. Humphrey has made with regard to the effect of temperature to go unanswered. The average temperature at eight o'clock in the morning for 40 days was 10° below zero, but before the end of the day we often had temperatures of 32° above, the records show 30° below zero at eight o'clock in the morning, and 40° above zero at noon. So that the question of the differences of temperature was fully met. When the concrete was uncovered on the morning after being placed in the forms, the cement was yet soft. With regard to the experiments made with this concrete and with the action of concrete in setting by freezing, the speaker has found invariably that neither freezing nor alternate freezing and thawing destroys; the chemical action of the change seems to be simply suspended. For instance, if you make a batch of concrete and let it freeze, when it thaws it is soft; but take the same stuff and put it into a temperature that is not freezing, and it will set up just as hard as if there had been continuous setting, at least that has been the speaker's experience.

The speaker even went so far as to take some of the concrete made in Vermont which had been frozen, but which had not been subjected to the process of steam, and when it was frozen perfectly hard, he allowed it to thaw and then put it into a temperature at which it would set normally. It took a longer time to set, but after it was thoroughly set, it was boiled and roasted and then seemed just as good as the sample of concrete spoken of.

In making concrete one most important axiom must not be forgotten, and that is, the whole cannot be stronger or better than its components. In making concrete to resist heat, limestone, or stone that will disintegrate with heat, must be avoided. Concrete made with cinders or ashes is, in the speaker's opinion, a vain delusion, a snare of the contractor and the ignorant architect.

In 1885 or 1886, the first large office building (iron construction) in Philadelphia was constructed, and it was laid in brick with cement mortar. Of course the exceedingly severe temperature of Vermont did not obtain, so the cement mortar was used warm, and the building is there to-day, as good as it ever was.

Within the last two months the speaker was obliged, in the setting of a boiler, to reject limestone in that construction, and he

Mr. Darrach. thinks that Mr. Lesley's remarks on the use of limestone should not be forgotten.

Prof. Talbot. A. N. Talbot, M. Am. Soc. C. E., Urbana, Ill.—The basis of the factor of safety given by Captain Sewell seems to the speaker to be correct, *viz.*, to base the strength upon the elastic limit of the steel and upon the strength of the concrete in compression at some point below its ultimate strength. Of course the relative amount of reinforcement and the quality of the concrete used will determine whether a test load will stress the steel up to its elastic limit before a given compressive stress is reached. To illustrate the different conditions as to tension and compression which may exist, let us look at the ordinary steel I-beam. It is generally assumed that the compressive strength of steel is the same as its tensile strength. However, it may be remembered that the statement is made by authorities that the compressive strength of steel is but little more, and sometimes no more—speaking of structural steel—than its elastic limit, while the tensile strength is considerably greater than the elastic limit. For that reason, the steel beam will fail at, or soon after, or not very far from, the point where the elastic limit is reached. The ordinary method of using the factor of safety in steel beams, based on ultimate tensile strength, does not carry us far into error, for we mentally reduce the factor of safety to the elastic-limit basis. In fact, based on ultimate compressive strength, we are merely using a factor of safety of one-half or two-thirds of what we talk about. When we come to reinforced concrete, a different condition exists. Assuming, without argument, that the tension of the beam is taken wholly or nearly by the steel, and that the concrete takes the compression, it may be readily seen that the load which develops the elastic limit of the steel is close to the full strength of the beam, provided the compressive strength of the concrete has not been exceeded. Of course, with a large area of steel reinforcement, the ultimate compressive strength of the concrete may be exceeded without the steel being stressed to its elastic limit. Just what proportion of the ultimate strength of the concrete should be correlated with the elastic limit of steel is an important matter. Captain Sewell's attitude on this point is commendable. This leads up to the requirements for the steel to be used for reinforcement, and the values of the elastic limit which may be expected for different grades of metal. The speaker is not prepared to discuss this, but it is an important topic.

One other point which has been brought out in these papers is whether the metal reinforcement adds to the tensional value of concrete. That there is such added strength seems to have been accepted quite widely. The experiments made at the University of Wisconsin show cracks in the mixtures used at a much earlier load

than the statement of M. Considère would indicate. In experiments at the University of Illinois, described in a paper before the American Society for Testing Materials, the load-deformation diagrams appear to indicate quite clearly, by the change in the characteristics of the diagram, when the steel has been stretched, say, $\frac{1}{1000}$ of its length that a change occurs in the stresses, which continues in a marked way until the steel and concrete are stretched to, say, $\frac{1}{300}$ of the length. Evidently between these two points, the concrete has lost a considerable part of its tensional value. This stretch indicates stresses in the steel of 3 000 and 10 000 lb. per sq. in. The concrete may have broken only in places; in fact, cracks were not generally visible with the naked eye until a stretch of about $\frac{1}{3000}$ was reached, and, in some cases, it was much higher. Such results go to show that at the loads usually given to reinforced concrete beams, the tensional effect of the concrete should be neglected. Prof. Talbot.

Professor Van Ornum has spoken about fatigue and the effect of repeated loads. Here is a field for investigation, not only to determine when the beam will break, but to find the condition of the concrete and of the steel when the load had been once applied and then taken off. Experiments seem to show that the steel remains under tension after the load is taken off, and that the net stretch may not be used when the load is applied as the basis of the tensile strength. Similarly, there is a question as to whether the apparent set on the compression side means that the stress has been entirely released.

The modulus of elasticity has been mentioned. It seems to the speaker that this is an important property of concrete in connection with beams, and that its importance has not been appreciated. It is understood that, in a general way, the stress-deformation relation of concrete is a curve rather than the straight line which obtains with materials where proportionality holds up to the elastic limit. That being true, the relation between the total deformation and the stress which produces it will be seen to be not a constant. How shall we express that relation? Captain Sewell's paper refers to the tangent of this curve as a hyperbola, if the stress-deformation relation is a parabola. The speaker has not examined the paper very closely, but it seems to him that the tangent line will not be of service in the calculation, but that what is needed is an expression which will show the relation between the actual amount of deformation and the value of the corresponding stress. To get this relation, the speaker has suggested the term, "initial modulus" of elasticity,* being the modulus of elasticity when the stress is first applied, corresponding to the tangent to the stress-deformation diagram at zero load. With this initial modulus, the relation between stress and deformation at any loading may be obtained.

* *Journal* of the Western Soc. of Engrs., August, 1904.

Prof. Talbot. In discussing what the stress-deformation curve actually is, the question arises whether the net deformation or the gross deformation should be used or, as it is frequently stated, whether the elastic deformation or the total deformation determines the work done. In the calculations for the Watertown Arsenal tests, everything is based upon the net deformation. When steel is stressed within its elastic limit, and the load is released, it is expected to go back very nearly to its original condition. This condition is not found to be true in concrete under compression or under tension. In fact, if a reinforced concrete beam is loaded and the load released, the beam will not resume its original condition by a considerable amount. Is this an actual set, using the word in the sense in which that term is ordinarily used, or are the concrete and the steel in a condition of stress after the load is taken off? Shall we start anew when a fresh load is applied? Using diagrams which were made in the experiments referred to and basing the stress in the steel upon the net or elastic deformation, the actual bending moment of the beam, due to the applied load, was found to be more than twice as much as the resisting moment of the beam calculated from the stress in the steel determined as above. It seems probable that the steel is in a state of tension after the load is taken off. What about the deficiency on the compression side? The effect of repeated loads upon the final strength of the beam is also an important topic for investigation.

Prof. Williams. GARDNER S. WILLIAMS, M. AM. SOC. C. E., Ann Arbor, Mich.— As an appendix to the remarks upon the fire-resisting qualities of limestone concretes, which are extremely apropos in this connection, the speaker would extend the same caution to the use of the ordinary granitic-drift boulders, where a fire-proof material is desired; for it must be remembered that granite is composed of three different minerals, each having a coefficient of expansion of its own, and it does not require the heat necessary to calcine limestone to cause this material to crumble to fragments by reason of the different expansions. In those localities where the drift boulder is the only available natural material, recourse must be had to vitrified brick, or hard-burned cinders when a fire-resisting concrete is wanted.

Mr. Fuller. WILLIAM B. FULLER, M. AM. SOC. C. E., New York City.— As Mr. Lesley has truly said, we are at the beginning of a new era in construction, the era of concrete construction, and it seems to the speaker that, at the beginning of such a new era, it is very important that we should start right in both theory and practice. Many elaborate theories on the strength of both plain and reinforced concrete have been evolved, but, after all, they are entirely dependent on constants derived from direct experimental results for their accuracy. It is, therefore, to the intelligent record of carefully conducted tests that we must look for information which will prevent

serious errors in design. Many tests are now being made all over the world, and it is necessary that each experimenter should realize that a careful description of the materials used and of the methods of mixing and testing is essential for the comparison of results. Tests on concrete which merely state the proportions of cement, sand and stone without a description of the materials and the methods used in measuring the proportions, have but little value to others working along the same lines, due to the great variation in the materials themselves, and again to the great variations in methods of stating proportions. Concrete proportioned by one person as 1:3:6 might be called 1:4:8 by another, owing to the use of different units for the unit volumes of cement, sand and stone. The relative sizes of the particles of sand and stone which go to make up the aggregate have also a very great influence on all the properties of a concrete, and two experimenters on identically the same quantities of materials in the mix might obtain widely divergent results, due to differences in the grading of the sand and stone. It is, therefore, very essential that, in all experimental work, the sand and stone be sieved through a graded series of sieves, and the amount passing each sieve recorded, so that, from this record, others can reproduce, if necessary, a material with the same gradation in sizes. Mr. Fuller.

It is well known that a mortar composed of 1 part of cement to 6 parts of sand is very deficient in strength, density and other desirable qualities, but by substituting stones for a part of this sand, using the same percentage of cement as before and making the proportions, say, 1:2:4, a concrete is produced having greatly increased strength, density and other qualities. It is not so generally known, but is nevertheless a fact, that the scientific grading of the sizes of the sand and stones used in making the mix will greatly increase the desirable qualities of a concrete.

With all these variables entering into the composition of any given concrete mixture, it is not to be wondered at that published results apparently vary so widely for the same nominal mix, and it is to be hoped that experimenters will realize what a variable compound they are dealing with, and give sufficiently full descriptions so that the particular materials they are using may be fully identified.

Rudolph P. Miller, M. Am. Soc. C. E., New York City.—Referring to the question of the fire-proof qualities of concrete, probably more study has been given to this matter by the building authorities in New York City than by any one else in the United States. Cinder concrete is extensively used in that city for the filling between the steel beams of fire-proof buildings and for the protective coverings of girders and columns. A great many tests Mr. Miller.

Mr. Miller. have been made under the supervision of the building authorities, and the fire-proof character of good cinder concrete is well established. The results on stone concrete have not been so satisfactory.

Roughly outlined, the test prescribed in New York consists in subjecting the floor construction, which formed the roof of a masonry structure or furnace, to a fire of 1 700° fahr. (927° cent.) for four hours, and then to a stream of water at 60-lb. pressure, through a $1\frac{1}{8}$-in. nozzle, for ten minutes, the floor being loaded during the entire test with 150 lb. per sq. ft. (about $7\frac{1}{3}$ kg. per sq. dm.), which was increased after the application of water to 600 lb. per sq. ft. To pass this test acceptably, no fire must pass through the construction; the load must be safely carried, and deflection after the removal of the final load must not exceed $2\frac{1}{2}$ in. in a beam span of 14 ft.

Eight tests on reinforced concrete construction, in which the aggregate was stone, have been made under these requirements. In two cases, the construction failed totally. In the other cases, the construction passed the requirements, but was so seriously damaged that from the fire-underwriters' standpoint, at least, it would be considered a loss. The concrete was in most cases badly cracked, and the metal reinforcement was exposed to such an extent as to preclude any possibility of restoring the integrity of the construction by patching. It is doubtful whether any engineer, considering it from a structural standpoint, would permit such a structure to remain, even though it had passed a satisfactory load test.

A general idea of the constructions tested and the results may be obtained from Table 2.

TABLE 2.

Test.	Concrete.			Reinforcement.	Result.
	Portland Cement.	Sand.	Stone.		
1.....	.....	.....	.....	Plain bars and stirrups.	Complete collapse.
2.....	1	2	4 Trap.	" "	" "
3.....	1	3	5 "	" "	Cracked.
4.....	1	3	5 "	" "	Badly cracked.
5.....	1	2	4 "	" "	Fair condition.
6.....	1	$2\frac{1}{2}$	5 "	Plain bars with stirrups attached.	" "
7.....	1	$2\frac{1}{2}$	5 Blue-stone.	Wire.	Spalled off.
8.....	1	2	4 Trap.	Rods and expanded metal.	Badly spalled off.

A very large number of tests have been made on cinder-concrete construction, and in no case was there a failure due to the concrete. In most cases, where failure did occur, it was directly attributable to bad design, insufficient reinforcement, or inadequate protection

of the metal against the heat. It must be remembered, however, that the concrete was, in all cases, used in connection with steel beams of sufficient strength to carry the loads, the concrete being used to fill the span between the beams. The spacing of the beams varied from 4 to 7 ft., the most usual spacing being 6 ft. While cinder concrete is an excellent fire-proof material, it is, at least as generally used, a very unreliable material as far as strength is concerned. It is, therefore, not a suitable material for true reinforced concrete construction. Mr. Miller.

The concrete mixtures in these tests were generally in the proportions of 1 of cement, 2 of sand and 5 of cinders. Portland cement was used in all cases. Other proportions were 1:2:4 and 1:1:6, and 1:4 in which no sand was used. The thickness of slab varied from 3 to 6 in. The reinforcement consisted sometimes of plain round rods, flat bars, small shapes such as tees or channels, wire and even sheet metal. In some tests, a concrete with slag as the aggregate was used. The results were quite satisfactory, but in this material again there is an unknown factor of strength.

In this connection, it may be interesting to refer to experiments made by the Bureau of Buildings on the conductivity of concrete. Blocks of cinder concrete and other materials, generally 2 in. thick, were placed over the fire-pot of a 6-in. gas crucible furnace in which the temperature was kept approximately at 1 700° fahr. for an hour, and the temperature of a cast-iron plate on the opposite side noted. The temperatures were read with a standard thermometer, the bulb of which was within $\frac{1}{8}$ in. of the surface of the plate adjacent to the material under test. In the case of the cinder concrete, the maximum temperatures read were 248° and 363° fahr.

In some of the floor tests referred to, the temperatures of the embedded steel beams or bars were also taken by a rhodium-platinum pyrometer. The results (in degrees Fahrenheit) are given in Table 3, and from them some idea of the conductivity of concrete may be determined.

TABLE 3.

Test.	Thickness of concrete, in inches.	Mixture.	Temperature of Metal, in Degrees Fahrenheit, after:		
			1 hr.	2 hr.	4 hr.
A	$1\frac{5}{16}$	1-2-5 Cinders.	258	297	.....
B	2	1-2-5 Trap rock.	239	448	750
C	2	1-2-5 " "	223	390	802
D	2	1-2-5 " "	156	203	342
E	2	1-2-5 " "	174	214	382
F	5	1-2½-5 Slag.	.....	.....	280
G	$1\frac{1}{2}$	1-2½-5 "	.....	240	600
H	$1\frac{1}{2}$	1-2½-5 Cinders.	135	512	875

Mr. Miller. The thickness given in this table represents the distance of the metal under test from the surface of the concrete exposed to the fire. The average temperature of the fire during all these tests was 1 700° fahr. In some cases, that temperature, however, was not reached as soon as in others, and there might have been considerable variation of temperatures during the tests. There were, too, variations in the density of the material. In tests, *A*, *G* and *H*, there was, in addition to the concrete protection, an air space of about $\frac{1}{4}$ in. between the concrete and the metal.

Test *A* was made in one of the fire-proof buildings under construction in New York City. A furnace was built in the building itself, around and under one of the main girders, in order to test the fire-proof covering of the girder. The covering consisted of slabs of cinder concrete, $1\frac{5}{16}$ in. thick, cast in moulds and secured to the girder by metal cleats. The slabs were made of Portland cement, sand and screened cinders in the proportion of 1, 2 and 5, in which expanded metal was embedded. The material was very compact. The test lasted two hours, and was made as above described for floor tests. The material proved very satisfactory. The maximum temperature of the lower flanges of the girder, as determined by a rhodium-platinum pyrometer, was 297° fahr.

In the tests, *B*, *C*, *D*, *E*, *G* and *H*, the beams supporting the concrete floor had a clear span of 14 ft. The entire length of the beam was subjected to the heat, and there was no opportunity for the carrying away of the heat as the beam rested on the masonry walls. In test, *A*, some of the heat may have been carried off by the steel frame of the building.

When it is recalled that the test made in 1896 at the Continental Iron Works showed that cast-iron or steel columns begin to fail when the temperatures reach about 1 100° fahr., it is readily seen that cinder concrete is a very satisfactory fire-proof material.

This is further corroborated by the fact that during the floor tests the deflection of the beam was never large. In test, *H*, for instance, where the maximum temperature was higher than in any other, the greatest deflection was $\frac{5}{16}$ in., which disappeared almost entirely after removal of fire and load.

The protection of iron against corrosion by embedding it in concrete has been referred to, and attention may be called, in connection therewith, to a paper read before the American Chemical Society, by Maximilian Toch, Assoc. Am. Soc. C. E.* He found that cement is not always a preventive of corrosion in iron embedded in it; that the ability of cement to prevent corrosion depended upon its freedom from iron; that from 1 to $1\frac{1}{2}\%$ of ferrous oxid in the cement would induce corrosion, and that steel embedded

* *Journal*, Am. Chemical Soc., May, 1903.

in cement containing such an amount of iron had actually been entirely destroyed by corrosion. Mr Miller.

OSCAR LOWINSON, ASSOC. M. AM. SOC. C. E., New York City.— Mr. Lowinson.
The discussion so far has brought out a number of precautions necessary in the use of reinforced concrete. The speaker will confine his remarks to his experience as a practising architect in New York City, who has been called upon to decide on the system of construction to be used in a fire-proof building. It may be worthy to note that the following conditions govern the choice for a system:

First.—Price;
Second.—Ease and speed of construction;
Third.—Its fire resistance;
Fourth.—The dead weight.

In 1903, the speaker was called upon to construct a fire-proof factory building and found that it was cheaper to construct the walls of brick than of reinforced concrete. He found it impracticable to use concrete columns or girders largely because none of the companies which do this class of work in this vicinity (where builders design details) could satisfy him that the loads coming upon the floors would be transmitted to the footings in the manner in which it was presumed they should. And right here the speaker desires to emphasize a weakness in concrete-steel construction, namely, that our designers have not yet been taught the necessity of carefully designing their details so as to transmit the load properly from one member to another. The speaker's attention has been drawn to the careful details of girder construction in several concrete systems, and he would not hesitate to use girders which are subject only to the stresses which he believes should be placed upon them. He is not yet convinced that a column composed of concrete with iron rods embedded in it should be used with greater allowable stresses than either the allowable strength of the concrete considered as a column plus the strength of the iron considered in compression, or a combination of these values, which will not exceed the sum of their individual values in direct compression. The speaker believes that this is in accordance with advanced thought on the subject, and he desires to warn the laity to beware of using the stresses which a majority of the companies installing these systems are apt to use.

Very little thought has been given by designers to the transference of loads, and too great caution cannot be exercised where an intersection occurs such as the point where a girder is sandwiched between superimposed columns. Attention should be directed to the danger of crushing the concrete where it rests on columns or walls. In other words, the bed should be so designed as to permit of deflection in the girder without diminishing its bearing either

Mr. Lowinson.

upon the wall or column, thereby endangering the concrete at the edge of the bearing.

Another point should be considered, especially where girders of greater length than 30 ft. are used, *viz.*, the effect of expansion or contraction due to variation of temperature. The speaker believes that a collapse occurred in 1903 due to the expansion of the girder under raised temperature and the deflection due to the load on the girder, the combination forcing the walls out and causing the consequent collapse of the structure.

Attention has been called to a high building constructed of reinforced concrete. The speaker would like to know the means by which the loads on the column rods were transferred to columns below and also the means adopted to transfer these loads to the footings.

The question of protecting the projecting flanges of structural members has been brought up, and the speaker is willing to record his faith in the efficacy of a thin protective shell. The speaker witnessed a large number of tests made under the auspices of the Bureau of Buildings of New York City some years ago, wherein a small building was roofed over with the floor system to be tested.* In no case was failure attributable to thin flange cover where the protection consisted of a layer of cement mortar laid on metal lathe, and the speaker is perfectly satisfied to use this form of protection where a system requires it. In fact, the only addition that he would suggest, and which is the result of his experience, is that a little lime be placed in the cement mortar; this makes it somewhat greasy and thereby tends to make the mortar work its way through the meshes in the metal lathe and be thereby keyed better. It will be remembered that in the fire tests mentioned, the temperature was maintained at from 1 700 to 2 200° for several hours, and that then a fire hose was played upon the surface which had been exposed to the fire so that the speaker would be satisfied with a ¾-in. protection on a metal lathe over ordinary flanges, say, of a width not greater than 8 in.

One other point the speaker desires to refer to and that is the ingredients of the concrete used. It is essential that limestone be not used for the broken stone, otherwise the conditions described by Mr. Lesley may be brought about, and there might be danger of the "fire-proof" building being a lime-kiln, because of the baking of the lime. If any stones are to be used for this purpose, *viz.*, the floor filling of reinforced girders and columns, care should be taken to avoid lime-stone, aggregate, or laminated stones. The materials to use are the igneous rocks, or, as Mr. Miller stated, cinders or trap rocks. The practice of using steam cinders has become almost universal in New York. Care, however, should be taken even with

* *Transactions*, Am. Soc. C. E., Vol. XXXIX, p. 147.

these. The composition is usually very poor, *viz.*, one part cement, three parts sand, six parts cinders. In practice this has been found to possess sufficient strength for its purpose. Mr. Lowinson.

There are a number of matters in connection with concrete-building construction, but these would interest the architect more than the engineer, such as moisture penetration, discoloration due to foreign matter in the concrete, and oxidation of the reinforcement, efflorescence, etc., so the speaker will not include them in this discussion.

G. N. Knapp, Esq., Madison, Wis.*—The speaker wishes to state an observation that he had opportunity to make in regard to the effect of fire on concrete structures. In the spring of 1904, he had the opportunity of examining two silos near Beloit, Wis., in the Rock River Valley. The silos were 25 and 30 ft. in diameter, respectively, and 40 ft. high, with concrete walls, 2 ft. thick. They were placed on opposite sides of a large barn, in which some 300 tons of hay were stored. The barn burnt, together with the hay, and the speaker had the opportunity of examining the effects of the fire on the concrete walls of the silos. Mr. Knapp.

The walls were built of concrete, using gravel and sand from a nearby bank of the Rock River. The ratio was 1 of cement to 7 of sand and gravel. The gravel contained 20 to 40% of limestone. This is a type of gravel common to Wisconsin and the Northwest. In building the silos, forms about 2 ft. deep were used, and the wall was carried up one form each day. After the fire, one could trace the line between the forms by the depth to which the concrete had scaled off. Along the line of contact between the forms, the concrete scaled off in large slabs leaving holes 3 to 5 in. deep, while, in the middle of the forms, where the concrete was more solidly packed, there was no scaling of the walls. These parts of the wall showed no effect of the fire except discoloration. The damage sustained by the concrete walls in this instance, as a result of the fire, was due to poor workmanship in handling the concrete rather than to the limestone contained in the gravel.

The speaker calls attention to this because, in the Northwest, concrete can be used with advantage in a great many structures, if the gravel of the region can be used; whereas, if crushed stone has to be brought from 100 to 600 miles, the cost would prohibit it. This particular instance would seem to indicate that concrete walls will stand such fires as are likely to occur on farms or in small towns, even when the gravel contains 30% of limestone, provided the work is well done.

H. F. Dunham, M. Am. Soc. C. E., New York City.—In the tests showing the degree of protection afforded by a thin covering, as de- Mr. Dunham.

* Agri. Engr., Agri. Experiment Station, Univ. of Wisconsin.

Mr. Dunham. scribed by Mr. Miller, it appears that not a very large area was subjected to the high temperature. Metals are good conductors and carry away heat rapidly. The fact that only 500° was noted in the metal may not be surprising, especially if metallic connections were favorable for conductivity and the time for exposure quite limited.

It is a common difficulty with laboratory tests and those on a larger scale, as in field exhibitions of the good qualities of fire extinguishers, that the conditions simulated do not always exist at the time of greatest need, when a fire occurs. The blazing combustibles in the test do not carry the number of heat units per cubic yard that are found where an apparently small fire has been slumbering for hours, and it is a question of heat units in both cases. The most satisfactory temperature test is the one comprising an extended area, where no small unit of surface under conditions favorable for radiation can give misleading results.

Mr. Goodrich. E. P. Goodrich, Jun. Am. Soc. C. E., New York City. (By letter.)—In reading the epoch-making papers on the subject of Concrete and Concrete-Steel, a few items on the subject have occurred to the writer, which he hopes will be of interest to the Engineering Profession.

Concerning the name given the subject, "Concrete-Steel," it is felt that while Captain Sewell is correct in that the words themselves are to some extent meaningless, still the combination, "Concrete-Steel," is shorter and more easily spoken and written than the term, "Reinforced Concrete," and when considered simply as a combination of the names of the elements entering into the construction, the term, "Concrete-Steel," seems sufficiently explicit, and a prophecy is hazarded of the ultimate major use of this term.

The uses of cement and concrete have become so diversified that one is hardly surprised even by the long and interesting lists given in the several papers. A large item, which has been omitted from the lists of both Captain Sewell and Mr. Thacher, in which Portland cement concrete has been used in the United States, is the numerous dry docks at the various navy yards. In them, almost the entire structures of several, and large portions of other docks, have been built of concrete by the civil engineers of the United States Navy. The following docks may be thus enumerated:

Portsmouth Navy Yard	No. 1
Boston Navy Yard	No. 2
New York Navy Yard	No. 2
League Island Navy Yard	Nos. 1 and 2
Mare Island Navy Yard	No. 2

Neither Captain Sewell nor Mr. Thacher has mentioned any works in which the concrete has been placed *en masse* under water,

and only the latter gentleman refers to such practice. Almost every engineer is acquainted with some one or two structures in which this has been done, sometimes with poor results to be sure; but the number of buckets now on the market, specially designed for depositing concrete under water, is a clear proof of the extent of this practice. It may be further noted that in sea-wall and other types of subaqueous construction, concrete in bags has also often been used with great success. Mr. Goodrich.

The vital element in all concrete being cement, every engineer is interested in its varieties, qualities and uses. The table given by Mr. Thacher, showing as it does that the maximum requirements of American Natural cement have probably been attained, and that the manufacture of the product is now falling off, is believed to be a strong argument in support of the fact found by the writer, and stated by many others of his acquaintance, that Portland cement concrete is cheaper than Natural, is stronger, often has advantages on account of quicker setting, and is, in many other respects, more reliable.

In such structures as dry docks and sea walls, the concrete used has not always been entirely satisfactory, however, and the subject, slightly touched upon by Captain Sewell, of the deterioration after setting, that is occasionally found in Portland cement concrete, due to exposure to sea water, is of great interest. Four years ago the writer, then a civil engineer in the United States Navy, inaugurated a series of tests to determine the qualities in Portland cements which are required to withstand successfully the action of sea water. No definite results were evident from the few experiments made, and furthermore, this is more properly a subject for the discussion of cement experts, except in so far as to acknowledge this undesirable quality of some Portland cements.*

The action of concrete or cement on the steel which is now so universally used with it, either as main member or reinforcement, is of vital interest. The writer's experience is that even rusty steel when embedded in cement becomes and remains bright. The cause of this is probably found in the chemical constitution of the cement.

The writer's attention was lately called to a case in which some expanded metal lath had been very badly eaten away by a patent wall plaster. This subject should be most carefully investigated by some chemical expert, and the benefit of his observations given to the profession.

Even if cement is the vital element in concrete, the other solid ingredients are of great importance and should receive hardly less study.

* A most interesting paper prepared by Mr. H. Le Chatelier for the International Congress of 1901 on the "Decomposition of Cement by Sea Water," of which there is a synopsis in *Engineering News*. Vol. XLVI, p. 108, gives the best information on the subject with which the writer is acquainted.

Mr. Goodrich. Most engineers have found difficulty in securing a good quality of cinders for use in building construction and fire-proofing work, and the writer has gone so far in several cases as to require, to secure a good article, the cinders to be screened and even washed, if necessary. This requirement has shown its value on numerous occasions.

Much has been written as to the relative value of gravel and stone in concrete, but the following may be of interest. During one series of tests carried out by an assistant of the writer's, a fact usually not believed was clearly shown. A large number of 12-in. concrete briquettes and beams, of gravel and of broken stone similarly treated, were prepared and broken. The average values for the gravel were higher than those for the trap-rock stone concrete. The fractures revealed in many cases that quartz pebbles had been torn asunder, while the angular fragments of trap were rarely broken.

The subject of mixtures of all sizes of sand and gravel is one in which the average engineer should take more interest. It has been the experience of the writer that a simple specification in which the cement is required to exceed the total voids of the mixture of sand and gravel or stone by, say, 20%, has been found simpler, easier to handle, and has produced cheaper and better concrete than that made according to the usual specification. To be sure, it is necessary that constant note be taken of the relative sizes of the ingredients, and that the actual voids be ascertained from day to day, as the material is found to vary in size. However, where gravel was used for the major part of the concrete, it has often been found that the sand encountered in the gravel bank has been exactly in the proper proportions to make an ingredient with the least possible percentage of voids. It is believed that such a specification as the above will be found to possess many advantages over the ones usually seen.

The last element, water, which enters into the combination in the making of concrete, cannot be overlooked, either as to its quantity, temperature, or chemical constitution.

The writer has made no quantitative tests concerning the use of wet and dry concrete, but has carried out several such qualitative tests. In one instance, several large blocks of concrete were prepared, some wet and some comparatively dry. The wet ones were found to require more material for the same size blocks (consequently were more compact), showed better fracture and absorbed less water. The writer's experience has shown that concrete which will barely flow when dumped from a height of perhaps 6 ft., has given most excellent results.

In some work done under the writer's direction in freezing

weather, the concrete ingredients were first mixed dry on a platform, and then water from the blow-off of an ordinary vertical boiler was blown over the surface of the thin layer of mixed ingredients. The concrete was then turned thoroughly and immediately placed, and the mass set in a most satisfactory manner, being warm to the feet for half an hour after being placed. During the same winter, several concrete blocks, about 12 by 12 by 36 in., were made, some with fresh water, some with sea water taken from New York Harbor, and some with brine mixed so as just to float an ordinary potato. The several blocks were left entirely in the open during the winter, and were carefully examined in the spring. The fresh-water blocks were practically worthless. Those mixed in sea water were passable, while those mixed with brine were excellent, except along some edges which appeared as if they had been subjected to a high temperature. On many occasions, where the temperature had fallen a few degrees below freezing soon after the concrete had been placed, the next day the walls were seen to thaw perceptibly under the action of the sun's rays, but during the course of the day would set up hard. This work proved perfectly satisfactory after having set in this way, by alternate freezing and thawing. Mr. Goodrich.

The work which Captain Sewell has done in commentating the Watertown Arsenal tests on the compressive strength of concrete, and in analyzing the various current assumptions as to the stress-strain curves in their light, is considered by the writer as a noteworthy addition to the literature of the subject. He is one of those, however, who believes in the practical use of the right line assumption.

It is of interest to add to the statement made by Mr. Thacher, that the Government Commission of Experts, which prepared the existing French regulations, the Prussian regulations, and the regulations of the Bureau of Buildings of the Borough of Manhattan, City of New York, besides neglecting concrete in tension, all stipulate that tests are to be based upon the assumption of the right line, as the stress-strain curve in compression of concrete.

It is to be noted that in the theories for reinforced concrete beams, as to whether the stress-strain curve is a parabola or a straight line, the variation in the depth of beam, according to various assumptions, is as follows:

Parabolic assumption	Captain Sewell's assumption	Right line assumption
40	45	48.

The normal variation in tests of exactly similar specimens does not usually fall within the variation here shown.

The determination of the other points of design in concrete-steel beams has not been so carefully considered. The spacing of

Mr. Goodrich

stirrups to take up shear has never been mathematically calculated, as far as the writer is aware, except in the design of the Parkville Sub-station for the Brooklyn Rapid Transit Railroad system, built by the Berlin Engineering and Construction Company, for whom the writer acted as Consulting Engineer. In the beams there used, the stirrups were vertical, were spaced closer together, nearer the abutments than at the middle, were of such size that usually several were required in a length equal to the depth of the beam, and were wrapped tightly around the tension rods, thus forming a sort of multiple-system Howe truss, wherein the concrete took the place of top-chord and compression diagonals. The idea embodied in this arrangement is believed to be just as logical as the system of Pratt truss bracing mentioned by Captain Sewell, and has numerous advantages over all others. Tests of beams so designed have shown their close conformity to the theoretical loadings for which they were built. Among other things, they showed that it was not necessary to have firmly attached stirrups; that a larger number of small-size round rods give better results than a less number of larger area; that plain round rods were really cheaper, per unit of supporting power, than most forms of patented or special reinforcement rods.

If it were the desire to use reinforcement rods of such diameter that their area of contact with the concrete would fully develop the tensile strength of the steel, wires of only $\frac{1}{20}$ in. in diameter would be required, on the basis of 500 lb. per sq. in. of adhesion between steel and concrete and 40 000 lb. per sq. in. of tension in the steel. This shows that better results are to be expected from a relatively large number of small rods than from an equal area of larger rods. All tests ever examined by the writer, in which such a comparison could be made, substantiate this supposition as a fact.

The writer has repeatedly observed fatal diagonal shearing cracks near the points of support of concrete-steel beams tested to destruction, even when such beams were built with stirrups, as usually designed. These cracks always appeared between the stirrups, which were seldom spaced closer together than the depth of the beam, as the stiffeners of a plate girder are usually arranged. The remedy is evident, *viz.*, use more stirrups of smaller size, placed closer together. With such an arrangement, it is not necessary to use attached stirrups according to one of the several patented methods, provided the ends of the tension rods are completely prevented from pulling into the concrete by some such means as used in the Hennebique system.

The method therein used, however, is not believed by the writer to be the best possible one. With such a treatment of the ends of the rods, it is not necessary to depend entirely upon the adhesion between the steel and the concrete to take up longitudinal shear, as

the concrete around the rods near their ends is thrown into compression, thus holding the stirrups in place. Mr. Goodrich

The advantages of the Howe system of trussing, above described, are further evident when rolling loads are to be considered, as counter-diagonals are not then necessary. The only point of importance is to design the vertical members with reference to their spacing from the ends as far as the middle, and duplicate the spacing symmetrically about that point upon the other end of the beam.

In the Parkville power-house, above referred to, concrete-steel crane girders were erected in accordance with the above method of design.

M. Considère's reference to the use of rods with rough surfaces, or with corrugations, raises a point to which the writer has given considerable attention, and to which allusion was made above, *viz.*, the relative cost of the various patented systems of rods, etc., with reference to plain round rods and with stirrups.

In every series of tests examined, the fact has been revealed that the cost of the steel per unit of ultimate load of beam or floor slab has been less with plain round bars than with any other kind of reinforcement on the market, except the Ransome twisted bar.

Concerning the latter, it is the writer's opinion that its smaller relative cost is due solely to the higher elastic limit of the bars, which is always found for some peculiar reason in bars treated in this way. In other words, the extra adhesive power claimed for all the patents is of less value than the extra cost of the special bar, and if round bars of an elastic limit as high as that in Ransome's bars were used, the smaller relative cost, of even the latter, would be reduced. The fact of the almost universal use of vertical stirrups in France is a good indication of their practical superiority to other varieties.

The writer heartily agrees with Captain Sewell in his contention that a factor of safety of $2\frac{1}{2}$ is ample for concrete-steel construction, if all parts of the structure are consistently designed.

As to the point raised by Captain Sewell of the superposing of compressive stresses, due to floor slabs and beams, and girders and beams, it is to be noted that the compressive stresses in the slabs near their points of support upon the beams and of the latter near their points of support upon the girders, are practically nothing, so that little is actually superposed.

Furthermore, near points of support, slabs and beams approach a condition of fixed ends, wherein the compressive stresses are transferred to the lower flange. The additional stress of the floor slab, which would be added to the girder, is also very small, because the slab becomes one supported on three sides in the vicinity of a girder, and the slab compressive stresses are thus *nil* close to it.

Concerning the reinforcement of concrete columns, the practice

Mr. Goodrich. always followed by the writer has been the use of longitudinal rods close to the surface, tied together at frequent intervals (closer together nearer the middle of the column) by wire ties passing completely around each rod and around the whole structure. He has been greatly interested, however, in a building erected in Brooklyn, N. Y., in which expanded metal has been rolled and securely fastened into cylinders, which act at the same time as reinforcements for the columns and as forms in which to place the concrete. The outer surface of these cylinders has been covered with regular wire lathing, to which a fire-proofing coat of cement plaster is to be applied. He is informed that the preliminary tested samples gave most excellent results, and believes that in this construction has been found a unique solution of many problems involved in the design of concrete columns.

The field covered by the applications of concrete and concrete-steel is a large and rapidly growing one, and one in which workers are needed and welcome.

Mr. Marsh. J. B. MARSH, ESQ., Des Moines, Iowa. (By letter.)—Mr. Thacher's paper is a timely contribution on a very interesting and important subject, and that portion relating to bridge construction is particularly interesting to the writer. While the paper fairly covers the subject, Mr. Thacher makes little or no mention of slab or concrete-steel girder construction. This type of structure is economical for short spans where the character of the foundations is favorable to its use. Where foundation work is difficult, the arch construction will, of course, give the minimum number of piers for a given length of bridge. The writer has built several concrete-steel girder bridges, using spans from 10 to 25 ft. in length. Two of these bridges contain three 22-ft. spans. One is made up of two 25-ft. spans. The last-mentioned is paved with brick, and has a double line of electric railway carrying 30-ton cars. The bridges, as built, make good structures at a very reasonable cost.

Under the heading, "Wet or Dry Mixtures," Mr. Thacher has cited the results obtained from experiments made by several eminent engineers, and his general deduction is that concrete should be a fairly wet mixture, but capable of being thoroughly rammed. While the writer heartily endorses this conclusion, the facts are, that, in field practice, it is very difficult, if not impossible, to get laborers interested enough in the work to tamp concrete thoroughly. A wet mixture makes a dense concrete, and unless the inspector watches the work closely, or an engineer who is interested in the work supervises it during its entire construction, the only sure method to get the concrete dense is to make it wet. Conditions in the laboratory and field are entirely different, and while the specifications may contemplate perfect workmanship, it takes eternal

vigilance on the part of some one person to carry out the spirit of the specifications. Mr. Marsh.

There will be much unsatisfactory concrete and concrete-steel construction. This must necessarily follow, when any contractor who is a low bidder is awarded the work whether he understands concrete construction or not. No set of specifications has ever been written that will hold a contractor whose only ambition is to make the maximum amount of profit. No qualifications are asked of him, and none can be expected. The writer knows of instances where faultless plans and specifications were adopted for concrete-steel bridges. The bridges, as built, are faulty; a result due to the avarice of the contractor and his ignorance of this class of work. The successful worker in concrete must be in sympathy with his materials. Concrete is honest with any builder who is honest with it, so the first ambition must be to produce the best results, the item of making money taking second place. The ideal contractor is, then, an engineer who is competent and honest. Given this class of men to execute the work, concrete and concrete-steel construction will rapidly grow in favor, not only with the Engineering Profession, but also with the general public.

Augustus Smith, M. Am. Soc. C. E., New York City.—A problem which constantly confronts the designer of structures of reinforced concrete is the safe value for the coefficient of adhesion. Much has been done, and many theories and methods advanced for computing the moment of resistance of a reinforced concrete beam at the point of maximum bending moment. Indeed, to judge from the literature on the subject, one would think that many designers of reinforced concrete beams were content to limit their investigations to the conditions occurring at the plane of maximum bending moment. Quite frequently reinforced concrete beams, designed to sustain uniformly distributed loads, are tested by concentrated center loads that will produce equivalent stresses at the plane of maximum bending moment. In some cases, such an investigation doubtless answers the purpose, but in the case of heavily loaded beams, especially for short spans, further investigation is desirable. Mr. Smith.

The horizontal or "flange" stresses in a beam, of course, increase progressively from the points of support to the point of maximum bending moment. The rate of increase is different for a uniformly distributed load and for a concentrated load, and varies with the position of a concentrated load. The rate of increase in these stresses is represented graphically by a parabola for uniformly distributed loads, and by straight lines forming a triangle for concentrated loads.

Now it would seem reasonable to analyze the stresses in a beam of reinforced concrete, in which the metal reinforcement is supposed

Mr. Smith. to supply the tensile resistance, in order to determine whether, for each infinitesimal unit of length of the reinforcing bar, the adhesion of the concrete to the bar, that can be safely allowed, is at least equal to the theoretical increment of tensile stress in the bar for the same unit of length. The portion of the beam where the increment of stress is greatest per unit of length should of course be selected for this computation.

This analysis is equivalent to the analysis of the stresses in a plate girder in order to determine the pitch of the rivets in the flanges; but it has seemed to the speaker that this computation, very ordinary in the designing of plate girders, has been quite generally overlooked in the designing of reinforced concrete beams, and that it might account for some of the cases that have been reported, of failure of concrete beams from "fatigue," so to speak, where a load has been applied and taken off repeatedly. In such cases, very likely the loads have caused increments of stress in the tensile reinforcement at certain points in excess of the adhesion of the concrete to the bar, and hence has allowed a minute local slip which has naturally increased with successive applications of the load until complete loosening of the reinforcement resulted.

A statement made by Mr. Goodrich, that many bars of small diameter give better results than few bars of large diameter, which will doubtless be corroborated by others, involves this matter of adhesion; for it is evident that the surface of the bar in contact with the surrounding concrete, and hence the value of the adhesion per unit of length of bar, varies with the diameter of the bar, whereas the cross-section of the bar, and hence the amount of tensile stress that it will probably be figured to carry, varies as the square of the diameter.

From this it is evident that with a fixed value for the coefficient of adhesion per unit of surface in contact, it would be very easy, in the case of heavy loads and short spans, to select bars for reinforcement of such large cross-sections that it would be impossible to transfer to them, within the limits of the span, the total tensile stresses that would be indicated by an analysis of the moment of resistance at the plane of maximum bending moment.

Another reason which has been pointed out for the comparative higher efficiency of small bars over large bars is that the diameter of the bar decreases as the bar is stretched, and, while the percentage of decrease in diameter for small and large bars is the same for the same tensile stress, the absolute shrinkage of the larger bar and hence the diminution of the value of the coefficient of adhesion of the concrete is evidently more than for the small bar.

The speaker believes that if reinforced concrete beams are analyzed as herein suggested, it will frequently be found necessary to utilize a mechanical bond by roughening or corrugating the bar

to assist the adhesion of the concrete, and especially will this be necessary in the case of heavy loads or short spans or when it is desired to use bars of comparatively large cross-sections rather than small wires. Mr. Smith.

To sum up, then, the speaker would point out that: stresses in concrete beams should be analyzed to insure adequate bond between the reinforcement and the concrete at every point of the length of the bar; reinforcement of small bars is preferable to reinforcement of large bars, first, because, with the former, the surface in contact is greater proportionately to the total tensile stress carried; and, second, because the absolute shrinkage of the diameter of small bars when stretched is less than in the case of large bars; mechanical bond is frequently necessary to assist the natural adhesion of the concrete; much additional information is needed to determine the safe value for the coefficient of adhesion under different circumstances.

Frank Beckwith, M. Am. Soc. C. E., Cleveland, Ohio.—In making formulas for the design of concrete-steel structures, there is one point which, so far as the speaker knows, has been overlooked, and which, in his judgment, should be carefully investigated. Mr. Beckwith.

Concrete shrinks in setting, perhaps $\frac{1}{1000}$ of the length of any side. Careful experiments should be made to learn the effect of this shrinkage upon the bond between the steel and the concrete, and also to learn whether this shrinkage does not set up an initial compressive strain in the steel.

W. K. Hatt, Assoc. M. Am. Soc. C. E., Lafayette, Ind.—There has been one matter of rather grave concern to those who are interested in reinforced concrete, and that is the point to which the steel may be stressed before serious cracks occur on the tension side of the beam. This involves a determination of what constitutes serious cracks. Prof. Hatt.

Considère's experiments indicated that, with the concrete used by him, and with the size of the test pieces used, the mortar in contact with the steel would extend 1 part in 1 000 before cracks formed themselves in the mortar.

Recent experiments in the United States show that very fine hair cracks develop in concrete at a period of deflection which corresponds to a stress in the steel of not over 2 000 to 3 000 lb. per sq. in. Indeed, minute fissures probably exist in the concrete before the beam is loaded. Some have gone so far as to say that the presence of the steel does not increase to any extent the extensibility of the concrete, and that fine cracks will appear independent of the presence of the steel.

It is evident that if these fine cracks develop at this early stage of the loading under favorable conditions with respect to the kind of

Prof. Hatt. concrete, in service conditions as well as under laboratory conditions, and, further, if these fine cracks are detrimental to the life and safety of the engineering structure, there is little economy in the use of concrete-steel.

However, conservative engineers have not hesitated to design structures, and many exist to-day, in which the steel is designed to carry as much as 16 000 lb. per sq. in. These structures have been in service long enough to make their usefulness evident. Such structures do not, from the speaker's knowledge, show any serious degree of cracks.

Laboratory tests made by the speaker on beams did not show cracks visible to the naked eye under an estimated stress of 20 000 lb. per sq. in. in the steel, and such cracks did not enlarge themselves so as to become serious until the elastic limit of the steel had been reached. This concrete referred to was made with a large percentage of crusher dust, and was thereby more flexible than the ordinary concrete from which crusher dust is excluded. As has been indicated, others find cracks at a much earlier stage.

In the face of such variations in results of experiments conducted under laboratory conditions, one should preserve an open mind with regard to this matter.

With regard to Dr. von Emperger's paper, it is noticed that on page 536 the strength of the beams is computed by using a factor of safety based on the ultimate strength of the steel. It seems to the speaker that factors of safety should be figured with reference to the elastic limit of the steel, for the reason that, in testing reinforced concrete beams, the beams are usually practically ruined at a stage of loading considerably below the ultimate strength of the steel. The most significant basis of comparison of the strength of two steel-concrete beams, at least for such concrete as is ordinarily used, is the elastic limit of the metal. As has been pointed out, the strength of a steel I-beam is reached when the elastic limit of the compression flange is developed.

The speaker desires to express his appreciation of Captain Sewell's paper, which is so excellent and well-judged a *résumé* of the state of knowledge at the present time. He is compelled, however, to take issue with Captain Sewell on the analysis of the relations between the modulus of elasticity and the compression diagram in the case of concrete. In Fig. 22, the results of such a test recently made in the speaker's laboratory are plotted, and the accompanying experimental data are given in Table 4.

It may be asked, what is the modulus of elasticity at the point, P?

1.—If we apply the load to the point, P, and back off, we arrive at a point, S'. There is then a "set," OS'. The distance, SS', is

the elastic compression. According to the speaker's view, the modu- Prof. Hatt.
lus of elasticity is

$$E = \frac{P\,S}{S'\,S} = 3\,500\,000 \text{ lb. per sq. in.},$$

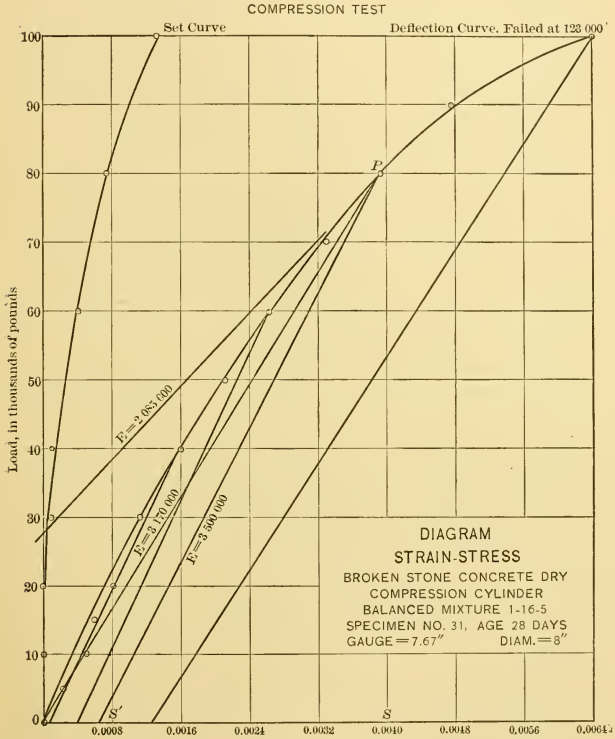


FIG. 22.

and, according to Captain Sewell, this should be the modulus, since he uses the elastic compression.

2.—If we draw a line, OP, the modulus may be defined as $\frac{P\,S}{O\,S'}$, as some have taken it, or 3 170 000.

3.—We may draw a tangent to the curve at P and call the slope

Prof. Hatt. of this line the modulus, or 2 085 000. This is evidently what Captain Sewell has in mind. Assuming the diagram to be a parabola with its vertex at O, he finds the modulus to vary as the ordinates to a hyperbola. The tangent follows this latter law.

So that it does not seem that the location of the vertex of the parabola at B, in Fig. 3 of Captain Sewell's paper, necessarily involves an absurdity, for he uses S to mean two different things in his analysis. That is to say, in Equation 1, S is supposed to be the total abscissa from the origin; and in Equation 2 S is the elastic compression, which is not the same distance. In fact, the Watertown tests, which are the final authority for Captain Sewell, use S more nearly according to Equation 2. There seems to be no necessary connection between E and F.

The speaker gives the results of many tests in Tables 5, 6 and 7, in which the E is obtained by "backing off." These tests were made in the laboratory for testing materials at Purdue University. In a test of steel, for instance, the backing-off lines are practically parallel to the ascending line drawn from the origin, except for the defect in elasticity due to overstrain. From these tables, there seems to be but little diminution of the modulus as defined by the first method used above.

It seems necessary to define what is meant by the modulus in a material like concrete before an agreement in conclusions can be reached.

TABLE 4.—Compression Test of Cylinder No. 31—Concrete.

Portland cement, 1; sand, 1.5; broken stone, 5; age, 28 days.

Gauge length, 7.67 in. May 8th, 1903.

Load, in pounds.	Micrometer Reading.			Set Micrometer Reading.			Mean Compression Readings.	Mean Set.	Mean Compression.
	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3			
00	0.4910	0.4669	0.3592	0.4910	0.4669	0.3592	0.4390	0.4390	.....
5 000	0.4908	0.4667	0.3591	.....	.....	.....	0.4388	.....	.....
10 000	0.4905	0.4663	0.3590	0.4910	0.4669	0.3592	0.4385	0.4390	0.0005
15 000	0.4904	0.4658	0.3593	.....	.....	.....	0.4384	.....	.....
20 000	0.4901	0.4652	0.3593	0.4910	0.4669	0.3592	0.4382	0.4390	0.0008
30 000	0.4900	0.4645	0.3591	.....	.....	.....	0.4379	.....	0.0011
40 000	0.4895	0.4640	0.3588	0.4908	0.4668	0.3592	0.4374	0.4389	0.0016
50 000	0.4889	0.4634	0.3585	.....	.....	.....	0.4369	.....	0.0021
60 000	0.4885	0.4623	0.3583	0.4905	0.4664	0.3590	0.4364	0.4386	0.0026
70 000	0.4877	0.4615	0.3578	.....	.....	.....	0.4357	.....	0.0033
80 000	0.4872	0.4607	0.3573	0.4902	0.4660	0.3589	0.4351	0.4383	0.0049
90 000	0.4865	0.4596	0.3567	.....	.....	.....	0.4343	.....	0.0057
100 000	0.4851	0.4580	0.3548	0.4895	0.4650	0.3588	0.4326	0.4377	0.0064

Failed at 123 000 lb.

TABLE 5.—Results of Compression Test on Concrete Cylinders, 8 In. in Diameter, 12 In. High, and 7.5 In. Gauge Length.

Broken Limestone; Crusher-Run Below 1 in. Mesh.

Reference Number.	Cement. Sand. Broken stone.	Condition.	Age, in days.	Yield point, in pounds per square inch.	Ultimate strength, in pounds per square inch.	Modulus of Elasticity, in Units of 10 000 lb. per sq. in. at Stress of:					Average.
						400	800	1 200	1 600	2 000	
14	1 - 2 - 5	Wet	90	2 000	2 268	765	.....	756	582	493	.....
14	1 - 2 - 5	"	90	1 600	2 710	507	555	505	467	380	.....
15	1 - 2 - 5	"	90	1 800	2 470	378	504	504	526	520	.....
Average	.....	.....	....	1 800	2 483	550	529	588	525	464	531
28	1 - 2 - 5	Wet	28	1 000	1 730	253	253	238	224	.....	.....
28	1 - 2 - 5	"	28	1 400	1 996	339	335	314	265	.....	.....
29	1 - 2 - 5	"	28	1 000	1 790	380	344	285	217	.....	.....
Average	.....	.....	....	1 133	1 836	324	311	279	235	.....	288
18	1 - 1.6 - 5	Plastic	90	1 600	2 590	377	377	352	321	294	.....
19	1 - 1.6 - 5	"	90	2 000	2 530	504	504	504	488	423	.....
20	1 - 1.6 - 5	"	90	1 600	2 610	380	405	482	468	435	.....
Average	.....	.....	....	1 730	2 576	420	430	446	426	384	421
20	1 - 1.6 - 5	Wet	90	1 800	2 985	.....	.....	.....	.....	.....	.....
21	1 - 1.6 - 5	"	90	1 600	2 430	504	467	455	467	380	.....
21	1 - 1.6 - 5	"	90	2 000	2 030	326	430	486	431	368	.....
Average	.....	.....	....	1 800	2 482	415	448	470	448	374	431
31	1 - 1.6 - 5	Plastic	28	1 190	1 730	337	338	350	293	.....	.....
31	1 - 1.6 - 5	"	28	1 000	2 430	383	409	488	383	300	.....
31	1 - 1.6 - 5	"	28	1 200	2 030	378	378	350	.....	.....	.....
Average	.....	.....	....	1 130	2 070	366	375	396	320	300	350
25	1 - 1.6 - 5	Wet	28	1 600	2 490	771	515	424	426	328	.....
26	1 - 1.6 - 5	"	28	990	2 030	.....	.....	370	317	270	.....
32	1 - 1.6 - 5	"	28	1 200	2 078	.....	334	348	280	352	.....
25	1 - 1.6 - 5	"	28	.....	2 598	440	441	441	375	328	.....
Average				1 263	2 296	.....	430	395	350	320	374

Prof. Hatt.

TABLE 6.—Results of Compression Test on Concrete Cylinders, 8 In. in Diameter, 12 In. High, and 7.5 In. Gauge Length.

Gravel; Pit-Gravel (including sand).

Reference Number.	Cement, Gravel.	Condition.	Age, in days.	Yield point, in pounds per square inch.	Ultimate strength, in pounds per square inch.	Modulus of Elasticity, in Units of 10 000 lb. per sq. in. at Stress of: 200	400	800	1 200	1 600	2 000	Average.
1	1–6	Wet	90	1 000	2 290	398	398	354	307	266	266	
1	1–6	"	90	1 600	2 690	....	438	512	438	408	382	
2	1–6	"	90	2 000	3 990	758	1 030	1 030	758	575	510	
9	1–6	"	90	.....	2 450	382	340	382	328	324	.....	
Average				1 550	2 855	513	551	570	460	394	396	474
26	1–6	Wet	28	1 000	1 890	256	....	.....	.....	.....	.....	
27	1–6	"	28	1 600	2 400	222	273	365	333	334	300	
29	1–6	"	28	1 400	2 590	379	379	432	415	552	323	
Average				1 333	2 293	286	326	398	374	443	312	371
5	1–5	Wet	90	1 200	3 520	....	754	432	432	418	420	
5	1–5	"	90	.....	2 289	....	606	760	760	716	695	
6	1–5	"	90	1 600	2 989	....	432	504	454	484	433	
Average				1 400	2 933	.....	597	566	548	549	516	555
7	1–5	Plastic	90	.....	2 240	767	439	438	418	350	306	
7	1–5	"	90	1 600	2 985	763	378	407	458	340	412	
4	1–5	"	90	1 000	2 650	....	502	335	335	325	343	
Average				1 300	2 625	(765)	440	393	403	338	354	385
23	1–5	Wet	28	3 000	3 280	310	388	443	455	413	370	
23	1–5	"	28	.....	2 100	387	....	345	292	310	267	
24	1–5	"	28	800	1 490	388	288	326	273	.....	.....	
Average				.....	2 290	362	388	371	340	361	318	356
22	1–5	Plastic	28	.....	2 330	468	520	390	360	.....	.....	
22	1–5	"	28	1 390	2 189	386	432	382	.....	.....	.....	
30	1–5	"	28	1 400	1 890	503	431	403	362	344	.....	
Average				1 395	2 136	452	461	392	361	344	.....	402

TABLE 7.—SUMMARY OF TESTS OF CONCRETE IN COMPRESSION.

KIND.					MODULUS OF ELASTICITY, IN UNITS OF 10 000 LB. PER SQ. IN.			ULTIMATE STRENGTH, IN POUNDS PER SQUARE INCH.		
Stone.	Condition.	Age, in days.	Number of Specimen.	Number of Determinations.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
1–2–5	Wet	90	3	14	531	765	378	2 483	2 710	2 268
1–1.6–5	"	90	3	10	431	504	326	2 482	2 985	2 030
1–1 6–5	Plastic	90	3	15	421	504	380	2 576	2 610	2 530
Average of all 90 days...				39	461	.....	.....	2 513	.....	.....
1–2–5	Wet	28	3	11	288	314	217	1 856	1 990	1 730
1–1.6–5	"	28	3	24	374	515	270	2 296	2 598	2 030
1–1.6–5	Plastic	28	3	13	345	488	200	2 070	2 450	1 730
Average of all 28 days...				48	335	.....	.....	2 067	.....	.....
Average of all stone.....					398			2 296		
Gravel										
1–6	Wet	90	4	23	474	1 030	266	2 855	3 990	2 290
1–5	"	90	3	15	555	760	420	2 933	3 520	2 289
1–5	Plastic	90	3	17	412	767	306	2 625	2 985	2 240
Average of all 90 days...				55	480	.....	.....	2 804	.....	.....
1–6	Wet	28	3	17	371	552	222	2 293	2 590	1 890
1–5	"	28	3	23	356	455	267	2 290	3 280	1 490
1–5	Plastic	28	3	20	402	520	271	2 136	2 333	1 890
Average of all 28 days...				60	379	.....	.....	2 239	.....	.....
Average of all gravel....					429	.....	.....	2 521	.....	.....

Average ratio of modulus in compression to modulus in tension = 0.92.
Average ratio of strength in compression to strength in tension = 8.5.
[For (1–1.6–5) and 1–5.]
Average ratio of modulus of wet mixture to modulus of plastic mixture = 1.08.
Average ratio of strength of wet mixture to strength of plastic mixture = 1.00.

Mr. Johnson. A. L. Johnson, M. Am. Soc. C. E., St. Louis, Mo.—Mr. Smith has spoken with regard to the point of adhesion, and perhaps some further information on that subject ought to be brought out. The point brought out by Professor Schüle bore directly on the matter of adhesion. In substance, his remarks were to the effect that when the reinforcing metal is stressed to several thousand pounds per square inch the section becomes smaller, and the concrete is of such a brittle and unyielding character that it takes very little decrease in that section to rupture the bond between the metal and concrete. As Mr. Humphrey has said, there is no chemical union between the concrete and the metal. The concrete simply enters slightly into the microscopical pores on the surface; and any very slight decrease in the section of the bar would be sufficient to rupture that sort of bond. In connection with plain material, the speaker can say this, that the Prussian Government specifications recently issued, covering all reinforced concrete work in the Empire, discriminate against plain material, although so far as he knows no other material has ever been used. These specifications contain a clause to the effect that the bond shall, so far as possible, be of a mechanical nature, and that where plain material is used the adhesion shall be figured at certain values, which are very conservative.

Two years ago, the tests of M. Breuillié showed that the continuous presence of water will greatly injure the adhesion of concrete to a metal surface.

The speaker has made quite a number of experiments of this nature, but has never felt that it was worth while for him to publish them, because of his well-known bias. He would rather get somebody else—some university—to take up the experiments, and probably that will be done. The experiments that have been made so far have been made on the bond without any attempt to subject the specimens to shock or vibrations, which should be done while the bar is under stress. This is a point which has not been mentioned, and one which in a case in the speaker's experience totally destroyed the structure in the course of seven or eight years' use. The floors of this building were put in about ten years ago. The speaker was called upon to examine them about eight years ago. The spans were only 8 ft. in length, the reinforced concrete slab being 6 in. thick. After eight years' use, these floors sagged 1½ in. Barrels of sheet glue, two high, were stacked on the floors, and when a barrel of glue was wanted, a top barrel would be dumped off. The barrels weighed about 150 lb. each. The dumping did not hurt the barrel, nor the glue; but, of course, there was a great deal of vibration in the floor, and after eight years of such use the floors were destroyed. When examined it was found that, although the con-

crete was of a very hard character, there was no adhesion whatever between the concrete and the metal. The metal was slipping in the concrete. The ends of the straps were hooked over the beams so that the floors could not go all the way down, but carried the load as a hog-chain. Mr. Johnson.

Abroad, plain reinforcement is universal; and this practice is often referred to as being sufficient warrant for such work in the United States. Foreign practice dates back of ours in the construction of tanks and circular sections where there is no tendency to rupture the bond between the metal and concrete; but we have been building beams longer than they have—since 1875, in fact. From ten years' experience, the speaker is prepared to affirm most positively that, in structures under shelter, where the concrete is very dry, the bond with the metal is of too brittle a nature to stand any great amount of vibration continuously; and in open-air structures the moisture absorbed from the air will reduce the adhesive value to not more than one-third of what it was originally. If the above is true, then certainly conservative engineers will either devise a reliable form of bond between the concrete and the metal, or else abandon the type altogether.

Professor Hatt has spoken of the extensibility of concrete and the difference between the results obtained in tests made by himself and M. Considère, and those obtained by Professor Turneaure.

The speaker has been present at a number of tests of reinforced concrete beams, and he is of the opinion that there were cracks in the concrete in those beams long before an elongation of 1 in 1 000 had been reached, as reported by M. Considère; but all concrete is not alike in this respect. There is the same difference between a thoroughly dried specimen of concrete and one which is subject to ordinary atmospheric conditions, that there is between wooden beams under similar conditions. The specimen subject to the open air and taking in a considerable moisture has a low modulus of elasticity. It has not so much strength, but great extensibility or compressibility. The dry specimen has great strength, but little extensibility or compressibility. Now, if the area of the stress-strain diagram in direct tension or compression is measured, and the work done by these two specimens is obtained, it may be found that the concrete which has an ultimate crushing strength of 1 500 lb. per sq. in. only, as against another which has a strength of 2 500 lb. per sq. in., has much the larger stress-strain diagram, and is capable of much more work.

If one will plot all the tests that have been made on concrete beams with whatever kind of reinforcement—provided only that the elastic limit is the same—it will be found that the strength of the beams is almost directly proportional to the percentage of metal

Mr. Johnson. reinforcement used between the limits of 0.5 to 1.5%; and independent to a surprising degree of the strength of the concrete where any of the usual mixtures and materials are used.

In obtaining the results of different tests, make the vertical co-ordinate $\frac{M}{bh^2}$—where M is the moment of resistance at the elastic limit of the metal, b is the width and h the height of beam—and the horizontal co-ordinate the percentage of metal reinforcement. By this means, the influence of the size of the beam is eliminated, enabling the tests to be plotted from various localities. Although the concrete may vary greatly in its character, the tests will plot very close to a straight line between the limits mentioned.

Professor Van Ornum has spoken about his impact experiments, and of his finding that repeated applications would break a concrete specimen with half the load originally required. He had rigged up an apparatus for subjecting a specimen to repeated applications of the load with no period of rest between. He cannot demonstrate that twice the factor of safety will have to be used for designing railway structures, for example, by tests of that sort; and the speaker is of the firm conviction that, if he will allow a fair time interval between the applications, he will not obtain such a result.

There has been some discussion as to what name should be given in English to this material, which the speaker only wishes to refer to casually. He first started to call it steel-concrete construction, because in 1901, at the Annual Convention of the American Society of Civil Engineers at Niagara Falls, that was what the Secretary, or the Board of Direction, called it, and it seemed to him a reasonable term. Mr. Thacher is in favor of concrete-steel, because there is more concrete than there is steel. That would be a good reason from a foreign point of view where the adjective comes last; but in English if you speak of paint, you do not say paint red, or paint black, but red paint, or black paint. This is a particular kind of concrete. If you accept it in that light, then it ought to be called steel concrete. As between steel concrete and concrete-steel, from an English point of view steel concrete is the better term, in the speaker's judgment. But there is no term that we can have that will be as concise and expressive as the French term *beton armé*. Our nearest approach to it is reinforced concrete, and the speaker is in favor of using that term.

Mr. Thompson. Sanford E. Thompson, Assoc. M. Am. Soc. C. E., Newton Highlands, Mass. (By letter.)—Captain Sewell's study of the elasticity of concrete is of exceptional interest because of its fundamental relation to the theory of reinforced-concrete beams. For the same purpose, the writer has studied stress-strain curves compiled from the various compressive tests recorded in the volumes of "Tests of

Metals, etc.," at the Watertown Arsenal, 1899, 1901, and 1902, and also the curves from cubes tested for Mr. Frederick W. Taylor and himself at the Watertown Arsenal. He has been impressed with the great variety in the shapes of the curves, which probably is due largely to the fact that in the 12-in. cubes the gauged length for measuring deformation can be only 5 in. It is worthy of notice that in certain cases the stress-strain curve is not a curve, but a straight line, almost to the breaking point, and therefore the modulus of elasticity in these cases is not a variable but a constant. Mr. Thompson.

Specimens selected at random from the tests of cement and mortar in "Tests of Metals, etc.," 1902, pp. 467 to 483, indicate that for a very dense mixture, such as neat cement or 1:1 mortar, the stress-strain curve is practically a straight line, while, as the porosity of the mass increases, it becomes more and more curved. A few results are presented in Table 8, where the modulus is calculated between the initial load, 100 lb., and the limit of the normal loading, and also between 100 lb. and a load about one-half this limit.

TABLE 8.—Modulus of Elasticity of Neat Cement and Mortar Prisms.

Dimensions, 4 by 6 by 24 in. Gauged length, 20 in. Age,* 2½ months.

Tests of J. E. Howard at Watertown Arsenal.

Brand of Cement.	Proportions.	Weight per cubic foot, in pounds.	Ultimate strength, pounds per square inch.	Modulus of Elasticity.				Decrease, per cent.
				Between loads, in pounds per square inch.	Modulus, in pounds per square inch.	Between loads, in pounds per square inch.	Modulus, in pounds per square inch.	
Alpha	1:0	135.5	Not broken.	100–1600	2 970 000	100–3000	3 020 000	−1.7
Peninsular	1:0	138.0	6 700	100–1800	3 820 000	100–3600	3 700 000	3.2
"	1:1	133.4	4 200	100–1600	2 970 000	100–3000	2 760 000	7.1
"	1:2	125.4	2 420	100–1000	2 400 000	100–2000	2 080 000	13.3
"	1:3	118.8	1 510	100–600	1 670 000	100–1200	1 430 000	14.4
"	1:4	113.4	900	100–400	1 280 000	100–800	1 010 000	21.0

* Alpha cement specimen was 1 month old.

It is also interesting to note that with the prisms used in these tests, which were about 4 by 6 by 24 in. long, tested with a gauged length of 20 in., the stress-strain curve takes its normal direction at the 100-lb. load, showing that these prisms do not present the characteristic of a very high modulus at low loads noted by Captain

Mr. Thompson.

Sewell for 12-in. cubes of concrete, and by other observers for 12-in. cubes of mortar.

Twelve-inch cubes of very highly compacted broken-stone concrete, tested at the Watertown Arsenal for Mr. Taylor and the writer, also show, in general, a straight line for the stress-strain curve from about 200 lb. per sq. in. up to the limit of the compression record. The concrete was mixed in proportions by volume (based on 100 lb. of cement per cu. ft.) of 1:2.3:4.6. In these specimens, however, as in the cubes tested by Captain Sewell, the same peculiarity of a high modulus below 300 lb. per sq. in. is noticed. The fact that this abnormally high modulus at low loads does not occur in the long prisms of neat cement and mortar appears to indicate that it may be due to the shape of the specimens and their short gauged length.

A typical stress-strain curve of the writer's cubes is illustrated in Fig. 23, and the modulus of each of the specimens is recorded in Table 9.

TABLE 9.—Modulus of Elasticity of 12-Inch Concrete Cubes.

Proportions, 1:2.3:4.6. Gauged length, 5 in.

Age.	Weight per cubic foot, in pounds.	Ultimate strength, in pounds per square inch.	Modulus of elasticity, in pounds per square inch.
1 month.....	151.1 150.4	4 370 3 360	3 840 000† 3 780 000
Average.....	150.75	3 865	3 810 000
2 months.....	151 149.5	5 430 3 940	4 150 000‡ 4 475 000‡
Average.....	150.25	4 685	4 312 500
17 months.....	153.2 147.0	5 510* 4 720	4 120 000‡ 3 692 000‡
Average.....	150.1	5 115	3 906 000

Note.—The difference in the strength of the specimens in each pair is due to methods of manufacture.

*Not ruptured.

†Substantially uniform between loads of 500 and 2 000 lb. per sq. in., the limit of the compression records.

‡Substantially uniform between loads of 200 and 2 000 lb. per sq. in., the limit of compression records.

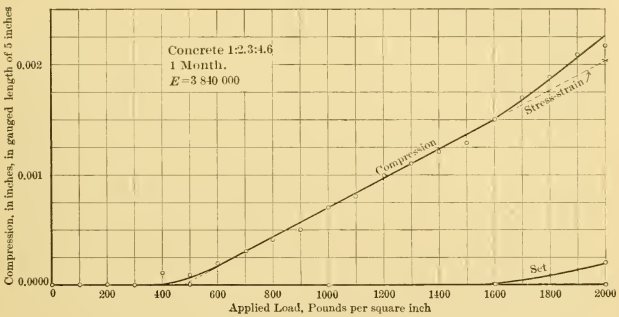
The very slight variation in the value of the modulus at different ages is noticeable, being almost within the limits of error

which might be expected in tests upon 12-in. cubes of the same material. The value of the modulus, about 4 000 000, is not presented as an indication of the value for average concrete, since the strength of the specimens is above the average. Mr. Thompson.

Another series of specimens, of similar proportions of materials, but mixed under different conditions, gave for the stress-strain curves, curves approaching the parabola. These latter specimens were more porous, that is, of less density than those referred to in Table 9, and showed much lower ultimate strength.

The writer believes that conclusions in regard to the true modulus of elasticity of concrete and the laws governing the relation of stress to strain at different loadings should be confirmed by tests upon specimens whose section is not less than 12 in. square, and whose length is not less than several feet, long enough, in fact, to

STRESS-STRAIN CURVE.



NOTE: In all other specimens the straight line, produced, intersected base at about 200 lb.

FIG. 23.

eliminate inaccuracies in measurement of deformation and the effect of the heads of the machine upon the ends of the specimen. A large section appears necessary to obtain a dense concrete. With exactly the same mixture of materials, the writer has found it practically impossible to produce 8-in. cubes which have as great density as 12-in. cubes. He finds, moreover, probably because of the inferior density, that 8-in. cubes invariably give lower unit strengths than 12-in. cubes.

W. D. PENCE, M. AM. SOC. C. E., Lafayette, Ind.—Reference has been made to the fact that we should be conservative in the interpretation of laboratory experiments, and that we should view the same with relation to the behavior of actual structures. Along the same line, as it seems to the speaker, the difference in conditions at Prof. Pence.

Prof. Pence. the time of construction and those in actual service ought to be taken into account.

For example, reinforced concrete fire-proof floors, reinforced concrete arches, and, in fact, all structures of this type now under discussion, may be built under conditions of very low temperature—adverse conditions, as they are generally considered from a construction standpoint—and later on, the conditions may be very different. So, in case of concrete floors that are put in at freezing temperature, there is one condition during construction, while later on those same floors in a heated building are subjected to widely different conditions. It seems to the speaker, therefore, that there may be set up, in this reinforced concrete construction, internal stresses which may perhaps often seriously tax the adhesion of the concrete to the metal. The temperature stresses may be very slight with small spans, but in many cases they may be of considerable magnitude.

The speaker has made some experiments in regard to the thermal coefficient of expansion of concrete, the experiments being conducted by a direct comparison of a steel bar with concrete bars; and, contrary to the commonly accepted idea, which is that the coefficients of steel and concrete are about the same, there is in reality a considerable difference between the two—a difference of perhaps 15% or more. The coefficient of expansion of concrete is 0.0000055, while that of steel is 0.0000065 to 0.0000070 per degree Fahrenheit. Taking that into account, with the fact that it is a very questionable practice to place dependence upon the adhesion of concrete to the metal, it would seem that the matter of temperature stresses should receive careful consideration.

In the discussion on the materials that are available for the aggregate of concrete, the idea was brought out that limestone may be a seriously defective material, owing to the fact that there may be calcination of the limestone in the concrete fire-proofing under the action of fire in a building. Reference was made to the desirability of using igneous rocks, either natural igneous rocks or those artificial substances which have had fire test or treatment. It seems to the speaker that in some cases the use of certain sandstones, which resist fire action well, would prove entirely satisfactory. Certainly, in some localities, the sandstones may be preferable to the limestones, provided the sandstone in the process of crushing does not go to dust too much, and provided its cohesive properties are satisfactory. A sample should be tested to find whether it will stand fire satisfactorily, and, in such case, the sandstone may very well be used as a substitute for limestone as an aggregate for concrete. The speaker has in mind a fire which destroyed all the combustible portions of two adjoining buildings.

Prof. Pence.

One building was built of limestone, the other of sandstone, and both were subjected not only to the action of flame, but to the severe effect of a fire stream while the materials were at a high temperature. The contrast between the behavior of the two materials was so striking that the speaker has been led to make these remarks in regard to the possibility of using sandstone for the purpose mentioned. The sandstone in this case stood the test exceedingly well, while the limestone suffered very severely.

Mr. Wentworth.

C. A. WENTWORTH, ASSOC. M. AM. SOC. C. E., Guantanamo, Cuba. (By letter.)—A more concise, impartial and comprehensive presentation of the field of "Concrete and Concrete-Steel" than Mr. Thacher's paper could not be made, and the writer can only add some cases from personal experience, which corroborate the views expressed.

CONCRETE.

Concrete from two to four months old, which was removed from the side walls of the Boston Subway, was very dense and hard, frequently splitting through the stones, where a wet mixture which would stand on a slope of about six to one was used. Adjacent concrete made of exactly similar materials and mixed comparatively dry and rammed was porous and easily broken up. A dry-dock abutment, which is one of the best pieces of dry concrete that the writer has ever seen, has every layer distinctly marked by a small seepage of water through the joint after the dock has been filled and pumped out, although, when dry, the joints are invisible except upon close inspection.

From these and several more examples which have been observed, it is believed that a wet concrete requiring but a very small amount of ramming to bring water freely to the surface has advantages in large monolithic work. Where several layers are to be deposited, the use of a mixture so wet that each successive layer will unite with the preceding one without ramming, will usually produce better results than where the concrete is dry and rammed hard. Where the latter method is resorted to, considerable segregation of the material in each layer usually occurs, and the adhesion of the porous part of the upper layer to the hard smooth surface of the lower one is very small.

CONCRETE-STEEL.

Several tests made on concrete-steel slabs and beams showed that, while the ultimate strength was increased by using steel with a high elastic limit, the first signs of cracking were observed before the stress in the steel had reached the elastic limit of ordinary soft steel. From these tests, the use of a material having a high elastic

Mr. Wentworth.

limit is of no real benefit, but on the contrary is open to the objections which have been raised against a high carbon steel for structural purposes. The damage which such steel sustains when bent or worked is sufficient to make the actual strength of structures in which it is used very difficult to determine.

Formulas.

A formula based upon the ratio of the moduli of elasticity of the steel and concrete for the maximum working load, the steel being assumed to take all the tension, is considered by the writer to be the nearest approach to a rational one, and the following tables and data which were prepared by him and adopted by the Bureau of Yards and Docks, United States Navy Department, Washington, D. C., may be of interest.

Standards to be Used in Designing Concrete-Steel Structures.

General.—All concrete-steel beams, girders, and floor slabs shall be so designed that all tension will be taken by the steel, the concrete being calculated as acting in compression only.

Concrete Mixture.—The concrete shall not be weaker than a 1 to $2\frac{1}{2}$ to 5 mixture, the broken stone, gravel, or cinders ranging in size from that which passes a $1\frac{1}{2}$-in. to that retained upon a $\frac{1}{4}$-in. screen, except for foundations where a 1:3:6 mixture may be used with stones up to 2 in. in size. All concrete shall be a wet mixture requiring but little ramming to cause the water to flush freely to the surface. Where granolithic is applied for a wearing surface, it shall be put on immediately after the underlying concrete is placed, and before it has begun to set, and worked into it so as to leave no line of division between the two. Work must be carried on in such a manner as to allow the granolithic finish to be put on and properly troweled over the entire area of each day's concreting operations before work for that day is stopped. An increase of 10% may be allowed in the compressive unit stresses for concrete floor slabs when finished with granolithic in this manner. An increase in the unit stresses given below for concrete may be made as follows: 1:2:4 concrete 10%; $1:1\frac{1}{2}:3$ concrete 20%. No allowance shall be made for granolithic finish when these higher unit stresses are used.

Unit Stresses.—The unit stresses shall not exceed the following, except as given above:

Beams, Girders, and Floor Slabs.

Steel:	
Tension	16 000 lbs. per sq. in.
Compression	12 000 " " " "
Shearing	10 000 " " " "

Mr. Wentworth.

Stone concrete:	
Compression	500 lbs. per sq. in.
Compression, granolithic top floors	550 " " " "
Shearing	75 " " " "
Adhesion to steel	50 " " " "
Cinder concrete:	
Compression	400 " " " "
Compression, granolithic top floors	440 " " " "
Shearing	60 " " " "
Adhesion to steel	40 " " " "
Columns.	
Compression:	
Stone concrete	300 " " " "
Cinder concrete	250 " " " "
Bearing of girders and beams on columns:	
Stone concrete	500 " " " "
Cinder concrete	400 " " " "
Modulus of Elasticity.	
Steel	30 000 000
Stone concrete	2 500 000
Cinder concrete	1 500 000

Formulas.—The following formulas are pertinent and useful in calculations:

f_c = Maximum fiber stress in concrete.
f_s = " " " " steel.
E_c = Modulus of elasticity of concrete.
E_s = " " " " steel.
d = Depth of beam (effective), in inches.
x = " " neutral axis below top of beam, in inches.
A_s = Area of steel per foot of width of beam.

$$R = \frac{E_s}{E_c}.$$

$$r = \frac{f_s}{f_c}.$$

For a beam 12 in. wide:

(1) $f_s A_s = \frac{12 f_c x}{2}.$

(2) $A_s = \frac{6 x f_c}{f_s} = \frac{6x}{r}.$

(3) $\frac{f_s}{d - x} = \frac{f_c E_s}{x E_c} = \frac{f_c R}{x}.$

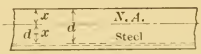


FIG. 24.

Mr. Wentworth.

$$(4)\quad \frac{x}{d-x} = \frac{R}{r}.$$

$$(5)\quad \frac{x}{d} = \frac{R}{r+R}.$$

(6) Moment of section $= 6 f_c x (d - \frac{x}{3})$ inch-pounds.

If the amount of steel is less than that given above, the moment shall be reduced in proportion to the reduction of the area of steel; if the steel is in excess of that given above, the stress in the steel shall be reduced so that the allowable unit stress in the concrete shall not be exceeded.

Tables.—The depth of the neutral axis, area of steel required, and bending moment of section per foot of width for varying unit stresses in the steel are given in Table 10. It is to be noted that decreasing the unit stress in the steel, the unit stress in the concrete remaining constant, lowers the neutral axis, and consequently increases the strength of the section.

TABLE 10.

Material.	x.	A	M.
	$f_s = 16\,000$ lb. per sq. in.		
Stone concrete	$0.273d$	$0.051d$	$744d^2$
Cinder "	$0.333d$	$0.050d$	711 "
Stone " , granolithic top	$0.292d$	$0.060d$	870 "
Cinder " , " "	$0.355d$	$0.059d$	826 "
	$f_s = 14\,000$ lb. per sq. in.		
Stone concrete	$0.300d$	$0.0643d$	$810d^2$
Cinder "	$0.364d$	$0.0625d$	767 "
Stone " , granolithic top	$0.320d$	$0.0755d$	944 "
Cinder " , " "	$0.386d$	$0.0728d$	888 "
	$f_s = 12\,000$ lb. per sq. in.		
Stone concrete	$0.333d$	$0.0833d$	$889d^2$
Cinder "	$0.400d$	$0.0800d$	832 "
Stone " , granolithic top	$0.355d$	$0.0976d$	1 033 "
Cinder " , " "	$0.423d$	$0.0931d$	959 "
	$f_s = 10\,000$ lb. per sq. in.		
Stone concrete	$0.375d$	$0.1125d$	$984d^2$
Cinder "	$0.444d$	$0.1066d$	908 "
Stone " , granolithic top	$0.397d$	$0.1312d$	1 138 "
Cinder " , " "	$0.468d$	$0.1236d$	1 043 "

Loads.—Where the live loads are applied rapidly and with considerable shock, they shall be increased 25% in the calculations. Floor slabs and beams shall be calculated for the full dead and live

loads, girders for the dead and 80% of the live-floor load, and columns for the dead and 60% of the live-floor load. All beams and girders shall be assumed discontinuous over supports, floor slabs as discontinuous over supports with a span equal to the clear distance between beams. Mr. Wentworth.

Details.—All floor slabs shall be jointed over the centers of beams and girders. Beams and girders shall be built continuously from the center of one girder or column to the next, the deeper one being recessed to receive the shallower one, unless both are built simultaneously. A section of floor slab equal to three times the width of the beam may be considered as part of the same, provided they are built simultaneously, and the longitudinal shearing stress in the combined beam does not exceed that allowed. If properly designed steel members are embedded in the concrete to resist the longitudinal shear, the allowable shearing stress shall be that of the steel and concrete combined. In general, rods should be placed a distance equal to $1\frac{1}{2}$ diameters from the outside of the beam and expanded metal or welded wire cloth from $\frac{1}{2}$ to $\frac{3}{4}$ in. from the surface. Rods of the Thacher or corrugated type, in which the sectional shape varies, may be calculated as having an adhesion equal to the shearing strength of the concrete. Where nailing strips are embedded in the concrete, they shall run at right angles to the beams, wherever practical. In case they run parallel to the beams, the net thickness of the floor slab shall be used in computations.

Columns.—Columns may be computed as having an area of concrete equal to the section of the column plus the area of the embedded steel multiplied by the ratio of the modulus of elasticity of the steel to the concrete. Columns shall have a diameter not less than $\frac{1}{12}$ of their unsupported length, with a rod placed near each corner and carried up to the top of the supported floor. If columns are continuous from one story to another, they shall have the steel rods lapped sufficiently to carry the stress from one to the other.

E. M. Scofield, Assoc. M. Am. Soc. C. E., Philadelphia, Pa. (By letter.)—Mr. Thacher has performed a good work for the busy engineer by bringing together under separate headings the results of practical experience which are recorded only in scattered articles in the engineering papers, if recorded at all. Mr. Scofield.

The wonderful increase in the use of concrete in the United States is well illustrated by the table which he gives showing the increase in the consumption of cement.

That reinforced concrete is an established industry, there can no longer be any doubt, and while the optimistic prediction, that reinforced concrete is destined to take the place of steel in all sorts of construction, is doubtless wide of the mark, there can be no doubt that the wonderful adaptability of reinforced concrete, the

Mr. Scofield. rapidity with which it can be constructed, and the permanence of the finished structure, will lead to its increased use in a great variety of works. The novel applications of it, in the last few years, have been such as to make one hesitate to set limits to its use.

The writer has for some years given much of his attention to the design and construction of reinforced concrete work, and believes that one of its greatest needs is careful attention to the practical details of construction. It is not sufficient that a structure be designed in harmony with the best practice and in conformity with the result of numerous experiments, but it is also necessary that the work be so designed that it is possible to construct it in harmony with the calculations. Many practical considerations, which are apt to be overlooked in the estimating room, are sure to impress themselves upon the engineer who has charge of the actual construction.

Tight forms are essential to the best results. Tongued and grooved material is frequently used for this purpose, but equally good results may be obtained by the use of square-edged plank, if the joints are caulked with oakum, or clay, or covered with tar-paper. For floor work, square-edged plank, with any open joints covered with a strip of tar-paper, will give excellent results; but if it is desired to plaster the work after the form is removed, the use of tar-paper is objectionable because it adheres to the concrete and prevents successful plastering. The use of oakum for caulking joints is without objection, and this is frequently less expensive than the use of tongued and grooved material, because square-edged planking can be used several times with entire satisfaction while tongued and grooved material is generally in poor shape after having been once used. A previous day's work is frequently injured by the careless removal of forms from the work, inasmuch as the concrete placed late the previous day has in the morning very little strength, and excessive jarring of forms may result in incipient cracks or checks which will permanently injure the work. Vertical forms, especially where any considerable depth of concrete is to be placed, should be carefully calculated so that they will not bulge under the strains produced by the wet concrete, as this bulging is apt to occur after some of the concrete has partially set, and the weight of the superimposed concrete may result in disrupting the partially set material after it is too late to retamp it. Wherever possible, the forms should be built complete before the bars or concrete are placed, so as to avoid all danger of jarring or distorting the forms before the concrete is thoroughly set. Floor forms, either in buildings or bridges, should be sufficiently stiff to allow the concrete to be tamped without appreciable deflection of the forms, as otherwise the placing of the wet concrete on one part of the floor will result in additional settlement of the forms under partially set

concrete, and thus slightly loosen the bars in this part of the floor. Mr. Scofield.
It frequently occurs in work of this kind, especially where the floor is thick and the final loads to be carried are considerable, that the swelling of the concrete in setting is sufficient to lift the slab off the form. The writer has had two cases of this in slabs, 10 ft. span and 4 in. thick, using Atlas cement and 1:2½:5 concrete. The slight swelling of the concrete was sufficient to relieve the form entirely of its load. This action was possibly aided in part by the unequal temperature in the slab, the upper part being exposed to the sun and the under part being in the shadow at the time the forms were removed.

In order to simplify the placing of bars in reinforced work, they should be spaced with as much uniformity as possible. The writer makes it a practice in his work to use a uniform spacing of 6 in., even at some waste of steel, wherever the nature of the work permits, but in thin slabs he aims at a spacing about equal to the depth of the slab.

While some experiments with plain bars embedded in concrete seem to indicate an adequate adhesion between concrete and bar, it is pretty generally conceded that the action of concrete in dissolving rust and loosening scale is such as to destroy this adhesion after the bar has been some time in place, and the prime consideration for reinforced work is, therefore, a bar which has a sufficient number of offsets to develop the strength of the bar independent of adhesion. It should also be as free from sharp angles as consistent with this requirement. In the practical work of placing concrete around bars, it will be found that freedom from flat spaces and sharp angles is a decided help in securing perfect contact between concrete and metal.

The general tendency toward a method of calculation which disregards the tensile strength of concrete, cannot fail to meet with the approval of the contracting engineer who is charged with the responsibility of getting his plans carried out faithfully in the field. It is one thing to make concrete tests in a laboratory and another thing to build practical work upon a large scale with ordinary human beings as workmen.

The Scofield Company in all its reinforced work makes a practice of inserting a sufficient number of bars for the load in the usual way, and then a smaller number of bars at right angles to these, in order to toughen the work. The writer believes this can be done in floors and arches with great advantage to the strength and toughness of the work, and the increase in cost is not sufficient to justify their omission. They offer a safeguard against the inefficiency of any particular bar, and serve to distribute local loads over a larger portion of the floor than could otherwise be done.

One of the most serious obstacles met in the practical carrying

Mr. Scofield. out of concrete-steel designs is the difficulty of keeping the bars in their correct position in the concrete. Many schemes have been used to overcome the disposition of foremen to place the bars on forms and then cover them with concrete, disregarding the fact that the engineer has calculated the strength of the floor on the assumption of $\frac{1}{2}$ or $\frac{3}{4}$ in. of concrete underneath the bar, as, for instance, the wiring of the bars up to temporary supports placed above the finished floor, or the placing of strips of wood on the forms to support the bars. The first is troublesome and not always satisfactory, and the latter is objectionable in that it leaves a portion of each bar exposed to moisture and diminishes the strength of the floor by the cutting out of a strip of concrete. The writer has secured good results by first placing over the forms a layer of mortar about 1 in. thick, and then laying the bars in this and afterwards placing the balance of the floor, carrying on the operations continuously so that the concrete has not time to set before the floor is finished. On large work, especially where longitudinal bars are numerous, this is troublesome and makes proper joints between different days' work difficult. The writer has also placed the entire system of bars and wired them together, and then supported them at intervals of 3 to 5 ft. upon small blocks, $\frac{3}{4}$ in. thick and 4 in. square. After this is done, a line of concrete is placed across the floor between these bars and tamped so that it flows around the bars and supports them, whereupon the blocks are removed, the balance of the forms covered with concrete, and the floor finished in the usual way. This method works with entire satisfaction if the foremen realize the necessity of getting all the blocks out, but they are quite as apt to think that blocks are a nuisance and might as well be taken out before they place any concrete, or else they forget to take them out altogether, so that the method is not, from a practical standpoint, what it should be. Robert A. Cummings, M. Am. Soc. C. E., has patented a sheet-metal spacer to be placed in the bottom of a girder form, which consists of a piece of sheet metal notched and bent down so as to leave recesses to receive the bars, and thus hold them at the proper distance from the bottom of the form and from each other. The Scofield Company has successfully used spacers made of wire formed as shown in Fig. 25, to support the bars at proper distances from the form and from each other, which are embedded in the concrete with a resulting increase of toughness. This spacer permits of the bars for an entire floor being placed in correct position with a minimum of labor, and is sufficiently strong to permit of the bars being walked on and wheeled over without displacement. When built into the floor, it adds to its toughness rather than otherwise, especially when the supporting loops are run up into the concrete so as to bind the bar into the

mass. Once the bars are properly placed on the forms by this method and inspected, there is no temptation on the part of the foreman to place the bars other than correctly. By placing these spacers sufficiently close and running the loops up near the top of the floor, the slab may be transformed into a concrete-steel "Howe" truss with solid web. This is useful at the ends of long spans when the shear is excessive. Mr. Scofield.

In placing bars for upright walls, the writer has found that the best results are obtained by placing all the bars and wiring them into position before any concrete is placed. Any attempt to adjust the bars in the upper part of the wall while the concrete is green in the lower part, is apt to result in partial fractures which will injure the strength and durability of the structure. This is especially apt

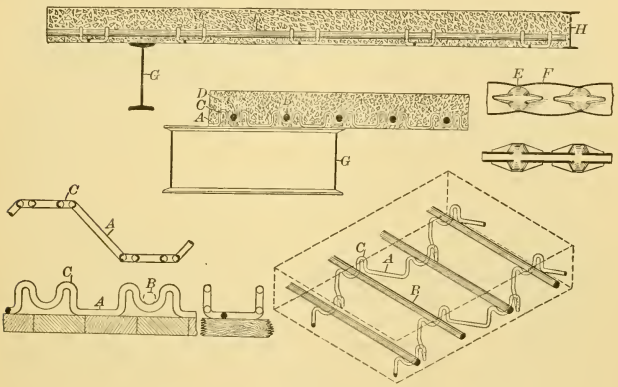


FIG. 25.

to occur when the foreman realizes the necessity of hustling and does not appreciate the engineering features of the construction.

The choice of materials for concrete that is to be reinforced, is a question of far more importance than for ordinary concrete. The size of the stone should be carefully graded in accordance with the nature of the work. In floors the best results are obtained by placing a layer of mortar on the form and following this with concrete, the stones of which will be jammed into the mortar so as to make a tough mass, and, at the same time, the mortar will be forced under all the bars so as to insure thorough adhesion and protection. Where, from the nature of the work, this is not desirable or possible, the stone should be small in size, and the concrete should be wet.

Mr. Scofield. The size and spacing of the steel, rather than the size of the member, should determine the size of the stone to be used, unless two grades of concrete are to be employed. The Scofield Company makes a practice of using ½-in. stone up to 6 in. thickness of wall, and ¾ to 1-in. stone up to 15 in. thickness of wall. A slight excess of mortar is a help in getting dense work and good adhesion. A 1 : 2½ : 4 concrete, or a 1 : 3½ : 6 concrete will generally give better results than 1 : 2 : 4, or 1 : 3 : 6, inasmuch as it is easier to get the material to flush tight around the bars, and it is possible to place the concrete with more water. In reinforced work which is to be trowel-finished, it is generally not possible to use as wet a mixture as is desirable for such work. Wherever the nature of the work will permit, the writer has found that he gets the best results when the concrete is made as wet as is possible without having the water run free, and he believes that working the concrete with a shovel or a rammer is preferable to tamping, as it works the air out and secures a solid mass of concrete without danger of jarring the bars which extend into partially set concrete. This method has one drawback on thin walls which are reinforced on both sides, and which are of necessity worked in the center, inasmuch as it tends to work the stone toward the surface and secure the densest concrete in the center of the wall, but the method has given uniformly good results on walls placed in this way.

A point which is seldom given due consideration in the design of reinforced work, is the necessity of stopping the work over night. This generally necessitates joints in floors, arches and walls, and it is seldom that this practical consideration receives the attention which it deserves, in the selection of the design. The writer makes it a practice to stop floor work in a vertical plane at right angles to the supporting girders, allowing the longitudinal bars, above referred to, to stick out into the next day's work. He has built considerable work where the attempt was made to get a dovetailed joint at these points, but in the majority of cases (say, on floors up to 6 in. in thickness), it is not desirable to do this, as a straight, clean joint will give stronger work, but it is necessary to get sound concrete along this division. It sometimes occurs that a joint has to be made between a girder and a column, and in all such cases the design should be such that the joint can be made in the center of the column. The Scofield Company recently built a system of reinforced walls to carry pressure from either side, where it was possible to place only one-third of the total height of the wall in one day's work, in which case the precaution was taken of placing an extra quantity of cement in the last few inches of wall and of starting the next day's work with a similar mixture, care being taken at night to clean all the projecting bars and level the concrete to a

square joint. It is generally impracticable to stop columns at any other point than the floor line, and in such cases the column bars ought to run up into the supported column a sufficient distance to develop the strength of the bars. Wherever possible, the writer believes continuous work to be best, but on large work this is not always possible without working at night, and even then interruptions are liable to occur; hence proper provisions for placing the work in detail should always be made. Mr. Scofield.

A good deal of uncertainty has existed as to the strength of concrete to resist shearing strains. It has been a common practice in the United States to use 75 lb. per sq. in. for shearing strains. The

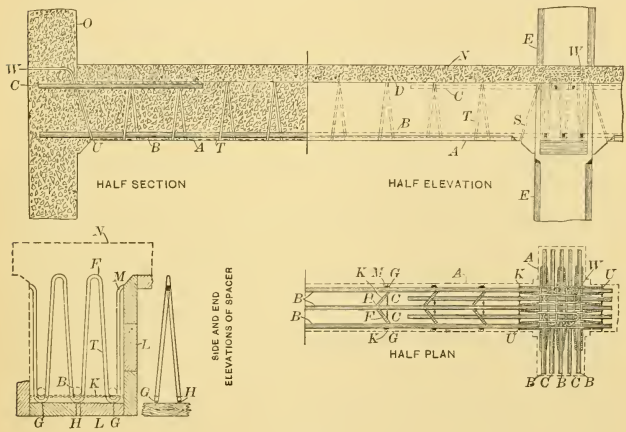


FIG. 26.

new German regulations provide for 64 lb., and some experiments would seem to indicate that even a less amount might be desirable when the actual conditions of field work are taken into account. The Scofield Company uses a spacing bar for beam work as shown in Fig. 26, by means of which a concrete-steel beam is resolved into a "Howe" truss with solid web. This spacer is used to maintain the longitudinal bars in their correct positions in the beam, and they are proportioned so as to allow a shearing stress on the concrete of not over 40 lb. per sq. in. The company finds that this extremely conservative unit for shear does not result in serious loss of economy since the spacer is used in any case to hold the bars in

Mr. Scofield. correct position. For vertical reinforcing, the spacers are placed at distances, center to center, about equal to the depth of the beam, and specially shaped spacers are used at column and girder intersections. Where bars are used in the top flange as well as in the bottom, these spacers hold the bars in position before any concrete is placed, and so make it possible to place the concrete continuously without danger of forgetting or misplacing the upper bars.

The writer does not consider it desirable to include the floor slab in calculation of strength of beam, except where absolute continuity of placing can be secured. It is generally much more feasible to place the concrete in the girder and afterwards in the floor, and, where this is done, he believes that the joint between the floor slab and the girder is not such as to justify the inclusion of the slab in the calculation of the girder. The spacers above referred to can be allowed to project above the beam and so serve to tie the floor slab to the girder in cases where it is necessary for any reason to include the floor slab in the calculation and yet impossible to place it at the same time the girder is placed.

Good results in finishing the surface of concrete are by no means so general as desirable. The writer has had best results by first scrubbing the surface with a wire brush so as to remove any loose particles of sand or stone and leave a strictly clean surface, then washing with a brush dipped in water and following this with the same brush dipped in pure cement grout, which is thoroughly scrubbed on with the brush till the cement takes intimate hold of the surface of the concrete, after which 1:2 mortar is applied in the usual way and troweled down. Where this is thoroughly done there need be no fear of cement cracking off unless exposed to the sun before it sets, in which case it will sometimes check where the coat is thick. A grout wash applied with a brush will also give a fairly good finish, and, if well rubbed on with a brush, will stick perfectly, if it is not frozen too soon after it is applied. No finish will stick on concrete work if the surface is covered with dust or small particles of sand. It is absolutely necessary that these be worked into a thorough grout by a brush dipped in cement, in order to make any application stick. For floors, the writer believes that it is impossible to get a thin coating, applied after the floor is set, to stick with any certainty because of the severe shocks and strains from trucks, etc., to which the floor is exposed, and he invariably insists that such work be placed continuously and the joint made square through the entire depth of the floor and at right angles with the lines of supports. The Scofield Company made some rough experiments of joints between gravel concrete where the joint was prepared, first, with water and cement grout in the usual way, and, second, with water followed by a steam jet using a thin narrow

nozzle and 80 lb. of steam, and then with the usual cement grout before the application of the concrete, and the results indicated that the joint was about 20% stronger in the case of the steam-prepared joint than in the case of the water-prepared joint. The concrete used was 1:3:6 gravel, and in both cases the weakest point appeared to be along the bottom face of the lower layer of gravel and not along the actual joint, the water-washed joint breaking on the actual joint on only about 25% of the surface tested, while the steam-prepared joint broke along the actual joint over about 1% only of the area tested. Mr. Scofield.

There can be no doubt that reinforced concrete offers one of the best materials available at the present time for many classes of construction, and its advantages over steel which is exposed to atmospheric influences are very great, but, from the nature of the construction, it requires conscientious execution in order to make it reliable. The making of steel has been reduced to such a basis that the purchaser is almost absolutely certain to get material which will be safe, and can, with very moderate precautions, obtain steel which is excellent, but the construction of reinforced concrete work cannot be inspected with any such success, and carelessness in execution may counteract the greatest excellency in design. The writer has recently seen reinforced work in progress where the bars were placed in forms, and wet concrete dumped on them, while the man tamping the concrete was expected to place the bars in their proper position by pulling them up part way by wires. The most careful inspector could not tell in what condition such a beam would be left. He has also seen joints, between the work of different days, in girders, made along the face of the column, so that the bars sticking out of the columns (to be embedded afterwards in the beam), together with the friction of the concrete along a joint many days old when completed, were compelled to carry the shear of the beam. He has also seen work in progress where the bottom layer of floor was placed, and bars placed upon it, and the balance of the floor left to be placed the following day. It is by no means an uncommon sight to see concrete-steel floors which show bars exposed along the entire bottom surface, showing that they were simply placed upon the forms, and the concrete placed over them in this position. In this position, the strength of the floors is, of course, largely reduced, and the bars exposed to rust. It may be that work is sometimes designed so that breaks of this kind are unavoidable, but greater attention to these details in designing would undoubtedly result in a better class of reinforced work, and such attention is certainly necessary to obtain the best results.

Sidney B. Williamson, M. Am. Soc. C. E., New York City. (By letter.)—Captain Sewell has presented a most interesting and in- Mr. Williamson.

Mr. Williamson.

structive paper on the subject of concrete in general, and has made many valuable suggestions from both a theoretical and practical standpoint. Not the least among these is the able argument against the injustice of requiring inordinately large factors of safety for reinforced-concrete members. A goodly number of methods, or theoretical formulas have been advanced for proportioning reinforced-concrete beams, all, however, having any claim whatever to rationality, are based on the fundamental theory of flexure, differing mainly in the constants assumed. That the general theory is safe and practical when properly applied is the opinion of the best authorities at home and abroad; moreover, this opinion is amply sustained by many recent tests and experiments. Admitting these facts, the present custom, generally in vogue with the building departments of municipalities, of requiring full-sized tests for different spans and approving the particular form of construction on these alone, certainly seems open to criticism. It is a very common statement among engineers, architects and others, that such tests are of doubtful practical value, because the structure to be tested is executed with infinitely more care than would be exercised on a similar one in practice. This is evidently true to a certain extent, as every precaution is naturally taken to insure success. It seems to the writer that it would be decidedly more rational for the building authorities to require that a formula be submitted with the application for the proposed method of construction, accompanied by the values of the constants to be assumed for different proportions of ingredients. It would then only be necessary to test the different mixtures of concrete proposed, to verify the value of the constants assumed, and eventually the results of these tests would form a valuable record, whereas the tests now made are of little, if any, general value. To go further, the department, if deemed necessary, could build and test a structure designed in accordance with the formulas submitted, charging the cost to the applicant. One test of this kind should suffice, however, and to obtain satisfactory results it should not end short of destruction or well-defined failure.

While the writer does not advocate going to the extreme and "drowning" concrete, his experience is somewhat at variance with that of Captain Sewell, in that the best results, especially in large masses of concrete, have been obtained with a mixture wet enough not to require ramming. One of the advantages of a wet unrammed concrete, that does not seem to have been brought out, is that a better bond is secured between the work of successive days. With a sufficiently wet mixture, the upper layer of broken stone is only partly covered, leaving a portion of each projecting above the plane of the matrix, and when the succeeding layer of concrete is deposited, the thin mortar runs through and effectually binds the

two courses. During the past three years, the writer has put in approximately 35 000 cu. yd. of concrete in fortifications, all of which was wet enough, when first deposited, for one to sink into ankle deep. Subsequently it became necessary to cut into the concrete at various places for telautograph niches, etc., and in no case was it possible to detect a joint. The general appearance of the exposed sections was excellent and was favorably commented upon by all who saw it. The extreme difficulty experienced in cutting the niches was a convincing testimonial of the good quality of the concrete, especially to the men who did the cutting. Another distinct advantage, that is possible only with wet mixtures, is that facing mortar is not required on the exposed vertical walls. In the work referred to above, as each layer of concrete was deposited, a common garden fork was thrust down the inside face of the forming so as to work the aggregate back, leaving a thin film of liquid mortar against the form. The result was eminently satisfactory for that particular class of structure, while the cost was nominal. Within the field of the writer's observation, the trouble from seepage is confined to the older forts built several years ago when the practice was to mix the concrete dry and ram it. In the fortifications on the New England Coast, recently built of wet mixtures, there is no seepage or leaks that cannot be traced directly to well-defined cracks. Referring to the method, mentioned by Captain Sewell, of finishing the extreme top surface of the concrete over the rooms with reinforced slabs of granolithic concrete, a somewhat similar method was used in finishing the platforms of a large battery at Fort Wetherill. The surface of the platform was divided by radial joints into slabs having an area of 300 or 400 sq. ft., and reinforced in both directions with ¼-in. rods. The joints extended down to the waterproofing about 12 in. below the surface, and were carefully caulked. The slabs were 12 in. thick, and were composed of the usual mixture of concrete to within about 2 in. of the surface; the finish was made of a granolithic mixture of cement and trap-rock screenings put on before the underlying concrete had set. There was only one small crack in these platforms when the writer last saw them, and at that time they had been finished about nine months and had been subjected to an unusually severe winter. Mr. Williamson.

The method, as described by Captain Sewell, does not seem free from objections. If the squares are small and entirely independent, as indicated, there is danger of their being displaced by the blast from the guns, and it would be better to make them larger in order to secure more weight and minimize the number of joints to be caulked.

The writer had occasion to investigate the case of corroded metal referred to by Captain Sewell. The latter's statement is somewhat

Mr. Williamson.

misleading, as not only the expanded metal, but the steel beams were corroded, and badly corroded. Tests of samples of both, made by the Pittsburg Testing Laboratory for the Engineer Officer in charge of the district, showed conclusively that corrosion was not due to impurities in the steel of either the beams or the expanded metal. The latter is cut exclusively from Basic Open-Hearth stock made of ingots from which the "sinking heads" containing the slag and other impurities are cut before heating for re-rolling. The material is worked over several times during the process of manufacture, and is finally rolled into sheets that must comply with rigid specifications as to strength and quality, so that the presence of impurities, to the extent suggested, would inevitably result in their being condemned. On the other hand, terne plate is an inferior tin plate, and a large portion of it is probably made of inferior stock, as the manufacturer will naturally dispose of such plates as will not fill the structural requirements, for this purpose. It is equally true that many of the terne-plate makers roll their own plates, sometimes direct from ingots. They are, therefore, worked over less and are more apt to contain metalloids than the structural metal. It is rather difficult to conceive that a piece of steel made at the present day by a reputable manufacturer may contain impurities that will insure its own destruction "regardless of any protective covering," and it would be interesting to know just how the destruction is to take place in a thoroughly protected piece.

The corrosion of the metals in this case was manifestly due to the porosity and ingredients of the concrete, which was composed of a natural cement, mixed comparatively dry with salt water and beach sand. The porous nature of the concrete is clearly indicated by the samples taken from the work, and is further apparent from the fact that rust streaks appeared on the lower face of the ceiling, which means that the rust penetrated the inch of concrete supposed to be below the metal. This is simply another case of metal having been placed in a damp location and inadequately protected, and, as in all similar instances, corrosion was inevitable.

Mr. Thacher.

EDWIN THACHER, M. AM. SOC. C. E., New York City.—Captain Sewell begins his paper by suggesting a change in the title of its subject, *viz.*, from concrete-steel to reinforced concrete. The speaker considers the term "Concrete-Steel" much the better, and more descriptive of the construction meant, although not a perfect definition. Nearly any non-specialist would conclude that the term "Concrete-Steel" meant some combination of these two materials, while the term "Reinforced Concrete" would give no such idea, as the reinforcement could be on the outside or inside, with any material, or in any manner. If, for instance, a concrete retaining wall is strengthened by wooden props or braces, it might be called a re-

inforced concrete wall, but it certainly could not be called a con- Mr. Thacher.
crete-steel wall.

Quite a number of examples are on record, which appear to show that the freezing, or alternate freezing and thawing of Portland cement concrete did not permanently injure it, and Captain Sewell states that he has had examples of that kind in his own work, but more cases where even a little frost has done undeniable damage. If the effect of freezing under identical conditions varies so widely, it appears to the speaker that it can be due only to the composition or character of the cement used, and as it is often highly important to lay concrete in freezing weather, comparative tests of cement cubes manufactured with each of the leading brands of Portland cement, frozen before setting, and tested, say, thirty days after thawing out, might be of great value and perhaps determine what brands of cement can be safely used in cold weather without any special protection, and what brands require thorough protection from frost. The speaker considers it more probable, however, that the difference in behavior is due to a difference in conditions, and whether or not it becomes frozen before or after intial set, or whether or not the frozen specimen contains uncombined water in the form of ice. This also can be determined by experiments.

JOHN S. SEWELL, Washington, D. C.* (By letter.)—The points Capt. Sewell.
raised by Mr. Thompson relative to the bearing of the length of a test specimen on tests for elastic qualities are worthy of determination by further experiments. The writer has examined a few tests in which the gauged length was 10 or 20 in. instead of 5. He did not discover sufficient departure from the characteristics shown by tests in which the gauged length was 5 in. to be worthy of comment. In any case, however, the initial part of the curve showing the relation between the stress and the modulus of elasticity is of minor consequence. As will be noted by reference to the writer's diagrams, in the deduction of practical conclusions, this initial portion of the curve was practically ignored.

In the case of the corroded metal, referred to by the writer, he himself visited the work where the corrosion occurred. At that time no appreciable corrosion of the beams had made itself manifest. There seemed to be considerable differences of opinion also among the overseers and inspectors who had been employed upon the work as to whether the cement used was Portland cement, Natural cement, or slag cement. In fact, it was very difficult to secure satisfactory evidence on any of these points. If the beams have also shown serious corrosion since the date of the writer's visit, it is rather a source of satisfaction than otherwise. The writer's opinion has been that the trouble was due to the fact that the concrete was

*Capt., Corps of Engrs., U. S. A.

Capt. Sewell. mixed with sea-beach sand, and possibly with brackish water; that it was probably not very dense, and was placed in a position where condensation insured an abundant supply of moisture. The porosity of the concrete and the salt contained in the water and sand would be sufficient explanation of the corrosion of the metal. It makes this explanation the more satisfactory if the beams have also shown corrosion.

Replying to Mr. Goodrich's comments, the writer is strongly of the opinion that a number of years ago he saw designs for reinforced concrete girders on the Hennebique system in which, after making a certain allowance for the shearing strength of the concrete, the remainder of the shear was taken up with vertical stirrups, the spacing of which varied according to the distribution of the shear. He is not able to say with certainty that this system was actually followed in the calculation, but he is quite certain that the design presented every appearance of having been so determined. About the time that the writer completed his paper on reinforced concrete referred to in this discussion, he also completed the design of some reinforced concrete floor systems for the War College building, in Washington, D. C. In this case, he analyzed the web stresses by analogy by a multiple intersection triangular truss, which he now considers a better analogy, where inclined stirrups are used, than a Pratt truss; it is more economical in the use of stirrups. In this design of the War College, he also endeavored to determine the section of stirrups so that the adhesion of that part of them above the neutral axis would develop their elastic limit, the idea being to relieve the concrete below the neutral axis of necessary structural duty as far as possible. The writer considers this of great importance in structures designed to resist fire. The writer cannot agree with Mr. Goodrich that our present state of knowledge will justify us in saying that the fastening of the stirrups to the main members is not necessary. Possibly it is not, but it seems much more logical to assume that it is. Thoroughly satisfactory experiments for determining this point have never been made. Until they are made, and until they show that it is not necessary to develop metallic connection between the stirrups and the main bars, the writer thinks it is much safer to assume that such connection is necessary, or, at least, highly desirable. Whether this result can be obtained without infringing certain existing patents is possibly open to discussion. It is to be hoped that before very long experiments will be made which will definitely settle the point.

In the matter of the superposition of compressive stresses in ribbed-floor systems, the writer has never made any appreciable allowance for this in any of his own designs, and agrees with Mr.

Capt. Sewell.

Goodrich that it is not generally necessary. He has heard the point raised and seriously discussed by a number of very able engineers, and knows of cases where this was a serious obstacle to the adoption of a system of reinforced concrete.

Recurring to the question of a factor of safety, the writer thinks that if Professor Van Ornum will carefully look into the question of the actual factor of safety in current designs for buildings, he will find that it is less than that proposed by the writer. The factor of $2\frac{1}{2}$ based on the elastic limit of steel will not ordinarily involve working stresses higher than 16 000 lb. For any sort of well made concrete, 2 000 lb. is such a conservative assumption for the ultimate strength that the writer thinks it is quite safe. As a matter of fact, his formulas, based on his assumed factor of $2\frac{1}{2}$, led to heavier designs than the majority of those current in reinforced concrete work at the present time. For railroad work or bridge work or in cases where heavy impact or vibration are inevitable, the writer would increase the factor of safety as a matter of course.

In the case of the steel rod used in the middle of some of the concrete piles at Washington Barracks, D. C., it is admitted that in this position the rod would not be as effective as a series of rods placed around the pile near its circumference, but the size of the piles and the method of putting them in made this latter distribution of metal almost impracticable. It is thought that, while the rod in the middle of the pile is not in position to render the maximum service, it, at least, makes the pile very much less likely to break across than if it were entirely without reinforcement. Only a few piles were reinforced in this way, as a matter of fact, because the conclusion was soon reached that no reinforcement was necessary.

In the mathematical work contained in the writer's paper, he invariably used only the elastic compression for the quantity, S. The curves plotted by the writer are of course arbitrary to this extent, that they merely connect various states of a practically discontinuous function. In plotting them, the elastic compression taken from the Watertown test was used in all cases, and elastic compression was assumed in all the equations. It would be impossible to obtain such curves by plotting the continuous record of any actual test, but it is thought that these curves represent as nearly as any others the actual distribution of the stress in the compressed part of the concrete after a certain amount of use in practice. No doubt, more tests are needed to enable us to deduce accurate results, and, as suggested by Professor Hatt, an agreement should be reached as to definitions before starting any discussion.

Since writing his paper, the writer has become convinced that the principal use of such formulas as those presented by himself should be for the determination of the maximum percentage of re-

Capt. Sewell. inforcing metal that could be used without developing the ultimate strength of the concrete. He is disposed to agree very largely with Mr. Johnson in what he says along this line. The formulas for both designing and testing reinforced concrete beams, whether of rectangular or T-section, could very readily be reduced to a form in which the external bending moment is equated with the resisting moment of the steel reinforcement, the lever arm of the steel being assumed at a certain constant percentage of its depth below the upper surface of the beam. As long as the percentage of steel is kept within safe limits, the writer thinks the question of working stress in the concrete can be entirely ignored without any sacrifice in safety and with great resulting simplicity in mathematical work.

Referring to the question of the effect of freezing on Portland cement concrete, the writer would add to what he stated in his paper, that the concrete he referred to as having been practically ruined was a reinforced floor slab. It is known that this slab was frozen within a few hours after it was placed. It remained frozen for six weeks without any thawing action extending beyond a quarter of an inch in depth from the surface. It was exposed to the weather and covered with snow a great part of the time. When, finally, the thaw came, the concrete was saturated with water. It was allowed to stand until it was very dry. Upon being tested, it was found that while it had an appreciable strength, it was certainly not more than one-half as strong as other concrete put in under the same conditions and in the same way, which had escaped freezing. The experience with this concrete slab seems to be at variance with that related by a number of engineers taking part in this discussion. The writer has had a number of experiences similar to those related by other engineers, but he thinks that one case where frost has done undeniable damage is sufficient to justify rather extensive precautions to prevent freezing, if it is possible to take them.

Dr. von Emperger. Dr. Fritz von Emperger, Vienna, Austria. (By letter.)—Professor Hatt says that in figuring beams of reinforced concrete the safety should be taken from the elastic limit instead of the ultimate strength of the steel. In this respect, it seems to the writer important to state that this limit cannot be exactly traced during a test because the indication of "first" cracks is, as repeatedly shown, too much dependent on the person making the test. The comparison made between a reinforced concrete beam and a steel I-beam seems to be misplaced in many respects, but especially because it refers to the limit on the compression side.

The writer can only state that in all his tests he has reached (with a low percentage of steel) the ultimate strength; and whether or not the test-pieces are actually broken depends only on how the steel is fastened in the concrete. As a very convincing example he

would refer to a test of bulb-iron having a section of nearly 6 sq. in., which had its lower flange broken by a bending test.* Dr. von Emperger.

The opinion mentioned by Professor Hatt has its source in tests made with beams which had not enough adhesion, so that the steel began to slide before the ultimate strength of the steel was reached. This side of the question was not treated as fully in the writer's paper as he would have liked, but, in the meantime, having published the matter as a separate book, with the title, "Ueber die Bolle der Haftfestigkeit im Verbunde,"† it is referred to here because it contains all the material which seems necessary for a final judgment.

It must not be overlooked that the figures for the ultimate stresses also depend upon the theory used in calculating the breaking load, but there are, in this respect, no such noticeable differences in steel as, on the other hand, are given for the compressive strength of concrete.

From the comparative tests recently made by the writer between Thacher iron and rough iron, he can fully endorse the opinion of Mr. Johnson that a perfect bond between steel and concrete is a necessity for good work of this kind, and, furthermore, that the carrying capacity of such beams is, under the circumstances, much greater than if only straight round iron is used. The theory of reinforced concrete beams cannot be considered as closed until the questions of shearing and adhesion are fully solved. The writer has strong hopes that this will be done shortly.

* *Beton und Eisen*, Nos. 3–4, 1904, p. 162, Fig. 74.

† "The Influence of the Bond between Concrete and Steel," published by W. Ernst & Sohn in Berlin; Forscherheft aus *Beton und Eisen*, No. 3.

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